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JOURNAL
OF THE
AMERICAN CERAMIC SOCIETY

A monthly Journal devoted to the arts and sciences related to the silicate industries.

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EDITORIAL

THE SEASON'S GREETINGS
WHAT SHALL THEY BE?

Our Society was conceived out of the great need for coöperation of Ceramists in Research. Under the far-seeing and inspiring leadership of Professor Edward Orton, Jr., this idea of coöperation was crystallized into the American Ceramic Society. After twenty-three years of consistent promotion of the fundamental principles and benefits of coöperation in technical and scientific research, we have reasons for rejoicing over the fact that many of the Ceramic Trade Associations are financing researches and that the ceramic manufacturers are coöperating.

This is the season of Good Will and of Resolutions. These are the fundamentals of coöperation. May each member of the Society give thought to what he can do to perfect the "team work" by which and only by which our Society can continue to be the stimulating and activating influence in coöperative ceramic research. The holding of conventions and the publication of records of researches is not sufficient. If more than this is not done by the American Ceramic Society some other organization will of necessity be formed. There is need for promoting coöperation between the producer and the user of ceramic wares and between each of these and the federal, collegiate and semipublic laboratories; and this promotion can best be secured by specialized groups, our Industrial Divisions, coördinated through the standing committees of the Society.

The American Ceramic Society is providing and must to a larger degree provide opportunity for the producer, the user and the laboratories to come together to report, discuss and record the results of the researches which each is supporting or conducting. This brings to the Industrial Divisions an opportunity. May each member of the Society, each Industrial Division, each Trade Association and each of the laboratories keep foremost the benefits of coöperation, coöperation between the producer, the user and the laboratories; and coöperation between the several Industrial Divisions within the Society. Coöperation is the carrying out of the principles of Good Will. Maximum coöperation requires a resolution on the part of each member of the Society to do team work with his fellow member on this Good Will program.

We must have the "best ever" convention in St. Louis, February 27th, and we must enlist a large number of ceramic workers and ceramic corporations in the support of this, the beginning and the end of organized coöperation, The American Ceramic Society. This convention and this membership campaign are occasions calling for the most perfect team work. The Program Committee and the Membership Committee need and ask for the assistance of every member of the Society. You will find inspiration for supporting the work of these two committees in "Good Will" coöperation in Research which the Society has developed and to which it must now give even more attention.

"Service" is the best of this Season's Greetings.

Ross C. Purdy

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ORIGINAL PAPERS AND DISCUSSIONS

THE MICROSCOPIC EXAMINATION OF THE MINERAL CONSTITUENTS OF SOME AMERICAN CLAYS[1]

By H. G. Schurecht

ABSTRACT

The difference in structure of the English and American clay grains and mineral constituents were examined under the microscope.

English kaolin consists chiefly of crystalline kaolin being similar to North Carolina kaolins in this respect. Georgia, South Carolina and some Pennsylvania clays consist largely of "colloidal" kaolin, which accounts for their difference in physical properties.

The objectionable abrasive features of the American clays causing excessive wear to machinery can be readily overcome by more "refined" refining methods but it is impossible by any present known methods or process to transform the colloidal kaolinite particles of our transported clays into the crystalline plate-like structure of the English china clay.

Our only hope therefore, of producing clays in this country which will be as satisfactory as those now imported, lies in the development of the crystalline kaolins. This is possible by better mining, blending and refining processes. However, the total tonnage of clay in our crystalline kaolin deposits is limited and if drawn upon intensively they would soon be exhausted.

Minerals found present in the clays are chiefly muscovite, quartz, tourmaline, biotite, zircon, alkali feldspar, plagioclase, rutile, hydrated silica and hematite.

Introduction

The average annual consumption of clays classed as kaolins and china clays in the United States, for the period of 1909–1918, amounted to 404,000 tons.[2] Of this sum 250,000 tons or 62 per

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[1] Received March 10, 1921. Published by permission of the Director, U. S. Bureau of Mines.

[2] Average from statistical data "Clay Working Industries, Silica Brick and Building Operations in the Larger Cities in 1918," by Jefferson Middleton, U. S. Geological Survey.

cent were imported, most of it coming from England. These clays find uses principally as fillers for paper, oil cloth and paint and for ceramic purposes.

Manufacturers maintain that it is necessary to use imported china clays for the better grades of paper, oil cloth and pottery and that the substitution of the domestic clays has not been entirely satisfactory. It is therefore evident that these imported clays possess desirable physical properties which have not been matched by our domestic clays. That these differences have not been entirely revealed by the ordinary laboratory tests is a well known fact.

American clays have been found which approach the English china clays in fineness of grain, plasticity, shrinkage, dry strength and color, but still the two clays behave differently when applied to commercial practice.

A comparison of the behaviors of English china clay and Georgia kaolin is of interest. The former clay disintegrates in water more readily, produces a body which casts more satisfactorily, gives lower drying and bisque losses, is less abrasive to oil-cloth and paper-making machinery, requires less linseed oil to produce a spreading condition for oilcloth and produces a paper of better finish and more resistant to moisture.

In endeavoring to explain the causes of these differences and to determine wherein the clays differed in structure, the Bureau of Mines undertook a microscopic study of the different sized grains of a number of clays in order to determine qualitatively the mineral constitution and physical character of the grains.

Although the work is not completed, it has progressed far enough to indicate that many of these differences may be attributed to the physical differences in the grains themselves.

The English china clays consist mostly of distinct crystalline plates and platy aggregates of kaolinite, whereas Georgia and South Carolina clays are constituted largely of "colloidal" kaolin aggregates. Clays constituted of crystalline plate-like grains and aggregates as compared to those made up of "colloidal" aggregates show a much lower adsorption and will therefore, disintegrate more rapidly in the blunger, require less water to place them in a plastic condition for jiggering or fluid condition for casting, will give up water more readily to the plaster mold and develop less drying strains. Due to lower adsorption, they also require appreciably less boiled linseed oil in order to place them in a fluid condition for spreading as oilcloth fillers, and as paper fillers they are less sensitive to a humid atmosphere.

The determination of the accessory minerals has also thrown considerable light on why some American clays are abrasive to oil-cloth and paper-making machinery. It has also thrown some light upon the possible origin of the clays.

A microscopic study of the clays fired to 1000°C frequently showed what minerals were responsible for the undesirable colors and served to indicate how such clays may be improved by better refining methods.

Experimental Methods

Each sample of clay was separated into nine different grain sizes by screening and elutriation[1] and each size examined separately under a petrographic microscope. The oil immersion method was used for determining the indices of refraction for identifying the minerals.[2]

The different grain size portions were then fired at 1000°C and their color noted by comparison with standard colors,[3] and the minerals causing the undesirable colors were examined under the microscope.

Results

English China Clays.—In Tables 1 and 2 are shown results of the microscopic examination of English china clays. Most of the kaolinite particles are present as platy crystals and aggregates of these plates, a feature which is characteristic of kaolins occurring near the mother rock. They can readily be identified by their indices of refraction, which lie between 1.56 and 1.57, and their low birefringence, 0.007. When examined on the flat side, some of these plates appear to have dark centers, due to their concave shaped faces, whereby they can be distinguished from muscovite.

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[1] *This Jour.*, **3**, 355–78 (1920).

[2] For more complete details regarding the use of the petrographic microscope for ceramic materials see, "The Mineralogical Examination of Clays," W. J. McCaughey, *Trans. Amer. Ceram. Soc.*, **15**, 322–27(1913). "Examination of Commercial Spar.," *Ibid.*, **15**, 381–87(1913).

[3] Ridgway, Robt., "Color Standards and Color Nomenclature." U. S. National Museum, 1912. Washington, D. C.

Muscovite and tourmaline are the most abundant accessory minerals. The muscovite is present largely as a fibrous mineral in which $\gamma = 1.583$ $\alpha = 1.560$. This mineral has properties nearer to sericite[1] than any other mineral and therefore was designated as sericitic muscovite.

Tourmaline can easily be identified by its strong pleochroism, negative elongation, parallel extinction and high index of refraction, γ being close to 1.64. Only a trace of alkali feldspar was found which was identified by its low index of refraction, which was less than 1.53. A trace of quartz was also found. This was identified chiefly by its index of refraction, 1.545, and + sign. When muscovite is calcined at 1000°C it appears very brilliant when examined in reflected light. Extremely small traces of muscovite may be detected in this manner.

Georgia White Clays.—In Tables 3, 4, 5, 6, 7 and 8 are shown the results of the microscopic examination of Georgia white clays. These clays contain a large proportion of extremely fine kaolinite differing from the English china clay which is composed of larger plates.

The fine kaolinite in Georgia clays is so fine that the particles can not be detected under the microscope even with a high power petrographic objective (Fig. 1). The index of refraction of this material is about the same as that for kaolinite, 1.563, and it was therefore called "colloidal" kaolinite to distinguish it from the coarser grained crystalline kaolinite, although no further tests were made to prove that this material was colloidal. Hydrated silica has an index of refraction of about 1.43 whereby it can be readily distinguished from "colloidal" kaolinite. Quartz and muscovite seem to be the most abundant accessory minerals. Small amounts of zircon and biotite are also present.

North Carolina Kaolins.—In Tables 9 and 10 are shown the results of the microscopic examination of North Carolina kaolins. These clays are similar to English china clay in that most of the kaolinite is present as platy crystals and aggregates of these

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[1] "Elements of Optical Mineralogy," N. H. Winchell. D. Van Nostrand Co., 1909, 288.

(Fig. 2). These crystals are more distinct than those found in the English china clay. However, the North Carolina kaolins examined are coarser grained than the English and have a poorer color when fired at 1000°C. They also contain more quartz. By applying better refining methods to these clays, it may be possible to obtain a substitute for English china clays since these clays consist chiefly of crystalline kaolinite.

South Carolina White Clays.—In Tables 11 and 12 are shown the results obtained with South Carolina clays. These clays are similar to Georgia clays being composed largely of "colloidal" kaolinite which is characteristic of transported kaolins. They, however, contain less quartz and muscovite than the Georgia clays.

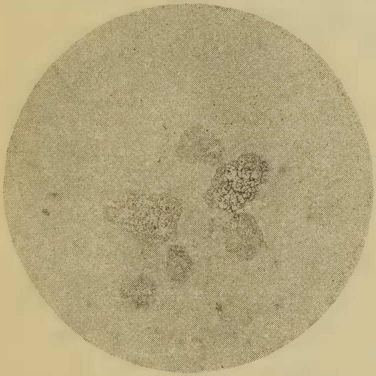

Fig. 1.—Georgia white clay. Magnified 40 diameters. Residue in can 1.

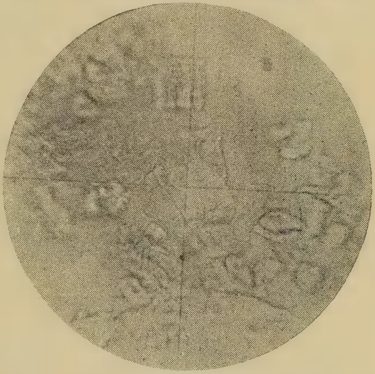

Fig. 2.—North Carolina kaolin. Magnified 250 diameters. Residue in can 1.

Pennsylvania White Clays.—In Tables 13 and 14 are shown the results of the microscopic examination of Pennsylvania clays. Sample 1.62 is similar to Georgia kaolin in that it contains mostly "colloidal" kaolinite, whereas sample 1.74 is similar to English china clay consisting chiefly of crystalline kaolinite.

The desirable properties of English china clays are evidently due to the fact that they are composed largely of crystalline plate-like kaolinite grains and are comparatively free from abrasive grains and objectionable coloring minerals when refined for market.

In conclusion the author wishes to acknowledge his indebtedness to Dr. W. J. McCaughey under whose direction this work was done.

Table I—1.01. English China Clay. Moore & Munger's, M & M

	Raw Clay				Clay Fired at 1000°C	
	Essential Minerals		Accessory Minerals		Color	Description
Sample	Most abundant	Considerable	Small amounts	Trace		
Can 1 5.93%	Cryst. kaolinite	Muscovite including sericitic muscovite	Tourmaline Quartz	Feldspar Zircon	Pale crimson pink Pl. XXIX 13″ f.	Coloring is due largely to iron-stained mica.
Can 2 2.70%	Cryst. kaolinite	Muscovite including sericitic muscovite	Tourmaline Quartz	Feldspar Zircon	Pale crimson pink Pl. XXIX 13″ f.	Coloring is due largely to iron-stained mica.
Can 3 18.08%	Cryst. kaolinite	Sericitic muscovite	Tourmaline	Quartz Spar	Pale pinkish cinnamon Pl. XXIX 15″ f.	Coloring is due largely to iron-stained mica.
Can 4 32.40%	Cryst. kaolinite	Sericitic muscovite		Tourmaline Quartz	White, very good	A trace of iron-stained mica is present.
Overflow 40.78%	Mostly cryst. kaolinite					

TABLE II—ENGLISH CHINA CLAY

	RAW CLAY				CLAY FIRED AT 1000° C	
	Essential Minerals		Accessory Minerals		Color	Description
Sample	Very abundant	Considerable	Small amounts	Trace		
20–65M* 0.04%	Quartz	Kaolin Muscovite			Black Brown & white	
65–100M 0.04%	Kaolinite		Muscovite	Quartz	Black Brown & white	
100–200M* 0.17%	Kaolinite		Muscovite	Quartz	Dark vinaceous drab Pl. XLV 5″ i.	Coloring is due largely to iron-stained particles of kaolin and quartz.
Can 1 4.00%	Cryst. kaolinite			Quartz Biotite Spar Zircon	Pale pinkish cinnamon Pl. XXIX 15″ f.	Coloring is due largely to iron-stained particles of kaolin and quartz.
Can 2 6.37%	Cryst. kaolinite		Muscovite Tourmaline	Quartz Biotite Spar	Pale pinkish cinnamon Pl. XXIX 15″ f.	Coloring is due largely to iron-stained particles of kaolin and quartz.
Can 3 16.15%	Cryst. kaolinite		Muscovite Tourmaline	Zircon Quartz Biotite Spar	Pale pinkish buff Pl. XXIX 17″ f.	Coloring is due largely to opaque particles which have a tan color in reflected light.
Can 4 15.58%	Cryst. kaolinite				Best white color	Characterized by the absence of colored particles.
Overflow 57.67%	Mostly cryst. kaolinite					

*20–65M stands for that material which passes a 20 mesh sieve and is caught on a 65 mesh sieve. 65–100M and 100–200M also refer to the sieves used.

TABLE III—1.37. WHITE CLAY FROM DRY BRANCH, GEORGIA

Sample	RAW CLAY				CLAY FIRED AT 1000°C	
	Essential Minerals		Accessory Minerals		Color	Description
	Most abundant	Considerable	Small amounts	Trace		
Can 1 5.95%	Cryst. & "colloid." kaolinite	Muscovite	Quartz	Zircon Rutile	Cartridge buff tinge Pl. XXX 19″ f.	Buff tinge is due to particles of iron-stained kaolin and colloidal matter. Cryst. kaolin appears white and translucent. Colloidal kaolin appears white and opaque. Muscovite appears transparent and iridescent.
Can 2 2.60%	Cryst. & "colloid." kaolinite	Muscovite		Quartz Zircon Rutile	Pale vinaceous fawn tinge Pl. XL 13″ f.	Buff tinge is due to particles of iron-stained kaolin and colloidal matter.
Can 3 6.60%	Cryst. & "colloid." kaolinite		Muscovite	Quartz Zircon Rutile	Tilleul buff tinge Pl. XL 17″ f.	Buff tinge is due to particles of iron-stained kaolin and colloidal matter.
Can 4 10.35%	"Colloid." & cryst. kaolinite			Muscovite	White with a cartridge buff tinge Pl. XXX 19″ f.	Characterized by the absence of colored particles.
Overflow 74.50%	"Colloid." kaolinite with small amts. of cryst. kaolinite			Muscovite	White with a cartridge buff tint Pl. XXX 19″ f.	Characterized by the absence of colored particles.

TABLE IV—1.38. WHITE CLAY FROM DRY BRANCH, GEORGIA

	Raw Clay				Clay Fired at 1000°C	
	Essential Minerals		Accessory Minerals		Color	Description
Sample	Most abundant	Considerable	Small amounts	Trace		
> 20M 37.2%	Quartz	Muscovite Kaolinite	Spar Biotite		Speckled brown, dark green & white	Red color is due to iron stained quartz. Greenish color is due to mica.
20–65M 4.0%	Quartz Kaolinite	Muscovite	Plagioclase Biotite	Zircon Rutile Tourmaline	Speckled yellow, brown & white	Yellow & brown colors are due to iron-stained mica.
65–100M 1.7%	Quartz Kaolinite		Plagioclase Biotite Muscovite	Zircon Rutile Tourmaline	Speckled yellow, brown & white	Color is due largely to iron-stained mica.
100–200M 5.5%	Kaolinite Muscovite	Quartz		Plagioclase Biotite	Speckled yellow, brown & white	Color is due largely to iron-stained mica.
Can 1 3.68%	"Colloidal" kaolinite Small amts. cryst. kaolinite			Zircon Muscovite	Pale vinaceous fawn Pl. XL 17''' f.	Color is due largely to iron-stained mica.

TABLE IV—1.38. WHITE CLAY FROM DRY BRANCH, GEORGIA (*Continued*)

	Raw Clay				Clay Fired at 1000°C	
	Essential Minerals		Accessory Minerals		Color	Description
Sample	Most abundant	Considerable	Small amounts	Trace		
Can 2 2.00%	"Colloidal" kaolinite Small amts. cryst. kaolinite			Muscovite Biotite	Best white tinge of tilleul buff Pl. XI, 17″′ f.	Characterized by the absence of colored particles.
Can 3 3.81%	Dirty "colloidal" kaolinite Small amts. cryst. kaolinite			Muscovite Biotite	Pale olive buff Pl. XL, 21″′ f.	Color is due to numerous black particles some of which are included in kaolin.
Can 4 12.60%	Dirty "colloidal" kaolinite with traces of cryst. kaolinite			Muscovite	Pale olive gray Pl. LI 23″″′ f.	Color is due to numerous black particles some of which are included in kaolin.
Overflow 29.45%	Dirty "colloidal" kaolinite					

TABLE V—1.40. WHITE CLAY FROM DRY BRANCH, GEORGIA

	RAW CLAY				CLAY FIRED AT 1000°C	
	Essential Minerals		Accessory Minerals		Color	Description
Sample	Most abundant	Considerable	Small amounts	Trace		
Can 1 10.85%	"Colloid." & cryst. kaolinite		Zircon Biotite	Muscovite Sericitic muscovite	Marguerite yellow Pl. XXX 23″ f.	Coloring is due to biotite, and black inclusion in colloidal kaolin. Also many black particles of unknown composition are present.
Can 2 5.65%	"Colloid." & cryst. kaolinite		Biotite	Zircon Muscovite Sericitic muscovite Quartz	White with a tinge of Marguerite yellow Pl. XXX 23″ f.	Coloring is due largely to black particles in colloidal kaolin.
Can 3 10.85%	"Colloid." kaolinite		"Colloid." matter probably hydrated silica	Biotite Muscovite Sericitic muscovite	White with a tinge of pale olive buff Pl. XL 21″ f.	Coloring is due largely to black and brown particles in colloidal kaolin.
Can 4 8.05%	"Colloid." kaolinite		"Colloid." matter probably hydrated silica	Muscovite	White with a tinge of pale olive buff Pl.XL 21″ f.	Coloring is due largely to black and brown particles in colloidal kaolin.
Overflow 64.60%	"Colloid." kaolinite		"Colloid." matter probably hydraulic silica			

TABLE VI—1.39. WHITE CLAY FROM DRY BRANCH, GEORGIA

Sample	RAW CLAY				CLAY FIRED AT 1000°C	
	Essential Minerals		Accessory Minerals		Color	Description
	Most abundant	Considerable	Small amounts	Trace		
100–200M 0.12%	Cryst. & "colloid." kaolinite	Muscovite				
Can 1 0.47%	Cryst. & "colloid." kaolinite		Muscovite Quartz			
Can 2 1.30%	Cryst. & "colloid." kaolinite		Muscovite Quartz Brown "colloid."	Zircon Biotite Rutile	Cartridge buff tinge Pl. XXX	Color is due to brown particles of biotite, rutile, and colloidal matter.
Can 3 9.24%	Cryst. & "colloid." kaolinite		Muscovite Brown "colloid."	Quartz Zircon Biotite	Tilleul buff tinge Pl. XL 17″ f.	Color is due to brown particles of biotite, rutile, and colloidal matter.
Can 4 13.63%	Cryst. & "colloid." kaolinite		Muscovite Brown "colloid."	Quartz Biotite	Best white pale olive tinge Pl. XL 21″ f.	Color is due to brown particles of biotite, rutile, and colloidal matter.
Overflow 75.35%	Mostly "colloid." kaolinite					

TABLE VII—1.33. WHITE CLAY FROM CLAYMONT, GEORGIA

	RAW CLAY				CLAY FIRED AT 1000°C	
	Essential Minerals		Accessory Minerals		Color	Description
Sample	Most abundant	Considerable	Small amounts	Trace		
100–200M 0.7%	Cryst. & "colloid." kaolinite	Muscovite	Quartz Zircon Biotite Tourmaline	Rutile	Tilleul buff tinge Pl. XL 17″ f.	Cream tinge is due to brown particles of biotite and brown colloidal matter. Kaolin appears white and opaque. Quartz appears white and translucent.
Can 1 6.83%	Cryst. & "colloid." kaolinite	Muscovite	Quartz Zircon Biotite	Rutile Tourmaline	Tilleul buff tinge Pl. XL 17″ f.	Color is due to brown particles of biotite and colloidal matter.
Can 2 2.20%	Cryst. & "colloid." kaolinite		Muscovite Quartz Zircon Muscovite	Rutile Tourmaline Biotite	Tilleul buff tinge Pl. XL 17″ f.	Color is due to brown particles of biotite and colloidal matter.
Can 3 10.68%	Cryst. & "colloid." kaolinite			Biotite Zircon	Best white	Characterized by the absence of colored particles.
Can 4 22.60%	"Colloidal" & cryst. kaolinite			Muscovite Biotite Zircon	Tilleul buff tinge Pl. XL 17″ f.	Color is due to iron-stained kaolin.
Overflow 57.00%	"Colloid." kaolin Small amts. of cryst. kaolinite					

TABLE VIII—1.23. WHITE CLAY FROM BUTLER, GEORGIA

Sample	RAW CLAY				CLAY FIRED AT 1000°C	
	Essential Minerals		Accessory Minerals		Color	Description
	Most abundant	Considerable	Small amounts	Trace		
100–200M 0.97%	Muscovite kaolinite	Quartz			Cartridge buff tinge Pl. XXX 19″ f.	Color is due to biotite which appears black and brown. Quartz appears translucent. Cryst. kaolin appears white and translucent. Colloidal kaolin appears white and opaque. Muscovite is transparent and iridescent.
Can 1 6.33%	Cryst. & "colloid." kaolinite Muscovite	Quartz	Zircon Black Opaque Unknown	Rutile Tourmaline Biotite	Ivory yellow tinge Pl. XXX 21′ f.	Color is due largely to black and brown biotite.
Can 2 37.90%	"Colloid." & cryst. kaolinite	Muscovite	Quartz Black Opaque Unknown	Rutile Tourmaline Biotite	Best white	Characterized by the absence of colored particles.
Can 3 6.91%	"Colloid." & cryst. kaolinite	Muscovite	Quartz Black Opaque Mineral	Biotite	Vinaceous fawn tinge Pl. XL 13″ f.	Color due to particles of iron-stained kaolin and colloidal matter.
Can 4 4.42%	"Colloid." & cryst. kaolinite			Muscovite	Vinaceous fawn tinge Pl. XL 13″ f.	Color is due to particles of iron-stained kaolin and colloidal matter.
Overflow 43.40%	"Colloid." kaolinite Small amts. of cryst. kaolinite					

TABLE IX—1.07. WHITE CLAY FROM JACKSON COUNTY, N. CAR.

Raw Clay					Clay Fired at 1000°C	
Sample	Essential Minerals		Accessory Minerals		Color	Description
	Most abundant	Considerable	Small amounts	Trace		
Can 1 12.0%	Cryst. kaolinite		Quartz Feldspar	Zircon Biotite	Tilleul buff tinge Pl. XL 17″ f.	The coloring is due largely to iron-stained mica.
Can 2 15.29%	Cryst. kaolinite	Muscovite	Quartz Feldspar	Biotite	Tilleul buff tinge Pl. XL 17″ f.	Coloring is due largely to iron-stained mica.
Can 3 18.93%	Cryst. kaolinite	Muscovite	Quartz Feldspar	Biotite	Tilleul buff tinge Pl. XL 17″ f.	The coloring is due to a large number of particles varying from yellow to red and black. The reddish brown particles are iron-stained mica.
Can 4 12.25%	Cryst. kaolinite	Muscovite	Quartz		Tilleul buff tinge Pl. XL 17″ f.	The coloring is due to iron-stained mica and yellow to black unknown.
Overflow 39.80%	Cryst. kaolinite					

TABLE X—1.41. WHITE CLAY FROM DILLSBORO, N. CAR.

	RAW CLAY				CLAY FIRED AT 1000°C	
	Essential Minerals		Accessory Minerals		Color	Description
Sample	Most abundant	Considerable	Small amounts	Trace		
20M 38.60%	Quartz Kaolinite	Muscovite Biotite Feldspar			Pink & brown	
20–65M 7.08%	Quartz Kaolinite	Muscovite Biotite Feldspar			Brown & white	The brown color is due largely to iron-stained mica.
65–100M 0.65%	Quartz Kaolinite	Muscovite Biotite	Feldspar		Brown & white	The brown color is due largely to iron-stained mica.
100–200M 5.80%	Cryst. kaolinite	Biotite	Quartz Muscovite Feldspar		Brown & white	The brown color is due largely to iron-stained mica.
Can 1 11.85%	Cryst. kaolinite		Biotite Quartz	Feldspar Muscovite	Pale vinaceous fawn Pl. XL 13″′ f.	The brown color is due largely to iron-stained mica.
Can 2 5.78%	Cryst. kaolinite		Biotite Quartz	Feldspar Muscovite	Pale vinaceous fawn Pl. XL 13″′ f.	The brown color is due largely to iron-stained mica.
Can 3 7.94%	Cryst. kaolinite			Biotite Muscovite Quartz	Pale vinaceous fawn Pl. XI 13″′ f.	The coloring is due to iron-stained mica.
Can 4 5.70%	Cryst. kaolinite			Biotite Muscovite Quartz	Pale vinaceous fawn Pl. XL 13″′ f.	The coloring is due to iron-stained mica.
Overflow 17.15%	Cryst. kaolinite					

TABLE XI—1.20. WHITE CLAY FROM LANGLEY, S. CAR.

	RAW CLAY				CLAY FIRED AT 1000°C	
	Essential Minerals		Accessory Minerals			
Sample	Most abundant	Considerable	Small amounts	Trace	Color	Description
100–200M 1.00%	Kaolinite					
Can 1 2.63%	"Colloid." & cryst. kaolinite		Rutile Zircon Muscovite "Colloid." Unknown	Quartz Tourmaline Biotite	White	Many brown particles are present, probably hematite
Can 2 11.21%	"Colloid." kaolinite Small amounts cryst. kaolinite		"Colloid." Unknown	Tourmaline Zircon Rutile	White very good	Brown particles are present due to hematite and iron-stained mica.
Can 3 22.74%	"Colloid." kaolinite Small amts. cryst. kaolinite		"Colloid." Unknown	Zircon	Best white	Characterized by the absence of colored particles.
Can 4 24.38%	Mostly "colloid." kaolinite				Very good white	Very few colored particles present.
Overflow 38.85%	Dirty "colloid." kaolinite				Light vinaceous fawn, Pl. XL 13″d.	Color is due largely to many brown particles, apparently hematite.

TABLE XII—1.14. WHITE CLAY FROM LANGLEY, S. CAR.

	RAW CLAY				CLAY FIRED AT 1000°C	
	Essential Minerals		Accessory Minerals		Color	Description
Sample	Most abundant	Considerable	Small amounts	Trace		
Can 1 12.05%	"Colloid." & cryst. kaolinite		Quartz	Muscovite including sericitic muscovite Zircon Rutile	Tilleul buff tinge Pl. XL, 17″′ f.	Color is due largely to iron-stained mica and hematite.
Can 2 7.40%	"Colloid." & cryst. kaolinite			Quartz Muscovite	Tilleul buff tinge Pl. XL, 17″′ f.	Color is due largely to iron-stained mica and hematite.
Can 3 1.65%	"Colloid." kaolinite Small amts. of cryst. kaolinite			Quartz Muscovite	Tilleul buff tinge Pl. XL, 17″′ f.	Color is due largely to iron-stained mica and hematite.
Can 4 10.90%	"Colloid." kaolin Small amts. cryst. kaolinite			Muscovite	Tilleul buff tinge Pl. XL, 17″′ f.	Color is due largely to iron-stained mica and hematite.
Overflow 68.0%	Mostly "colloid." kaolinite					

TABLE XIII—1.62. WHITE CLAY FROM SAYLORSBURG, PA.

Sample	RAW CLAY				CLAY FIRED AT 1000°C	
	Essential Minerals		Accessory Minerals		Color	Description
	Most abundant	Considerable	Small amounts	Trace		
20–65M 0.9%	Kaolinite	Quartz			Light mouse gray Pl. Ll 15″″′ b	Coloring is due largely to impurities in quartz and kaolin aggregates.
65–100M 0.66%	Kaolinite	Quartz			Light mouse gray Pl. Lz 15″″′ b	Coloring is due largely to impurities in quartz and kaolin aggregates.
100–200M 4.20%	Kaolinite		Quartz		Smoke gray Pl. XLVI 21″″ d	Coloring is due largely to impurities in quartz and kaolin.
Can 1 2.62%	Cryst. kaolinite Small amts. "colloid." kaolinite		Zircon Quartz Tourmaline Black Unknown	Biotite Muscovite	Tilleul buff Pl. XL 17″′ f.	Coloring is due largely to impurities in quartz and kaolin. Iron-stained mica and hematite are also present.
Can 2 2.94%	Cryst. kaolin Small amts. "colloid." kaolinite		Zircon Quartz Muscovite Black Unknown	Biotite Tourmaline	Pale olive buff Pl XL 21″′ f.	Coloring is due to brown particles of iron-stained quartz, kaolin and mica. Hematite is also present.
Can 3 10.50%	Cryst. & "colloid." kaolinite		Quartz Black Unknown	Biotite Muscovite Zircon	Cartridge buff Pl. XXX 19″ f.	Coloring is due largely to iron-stained mica and hematite.
Can 4 14.13%	Cryst. & "colloid." kaolinite		Black Unknown	Biotite	Cartridge buff Pl. XXX 19″ f.	Coloring is due largely to iron stained mica and hematite.
Overflow 64.40%	Mostly "colloid." kaolinite		Black Unknown		White very good	Characterized by the absence of color.

TABLE XIV—1.74. WHITE CLAY FROM SAYLORSBURG, PA.

	RAW CLAY				CLAY FIRED AT 1000°C	
	Essential Minerals		Accessory Minerals		Color	Description
Sample	Most abundant	Considerable	Small amounts	Trace		
Can 1 10.06%	Cryst. kaolinite	Quartz	Tourmaline		Light mouse gray Pl. LI 15″″′ b.	Coloring is due largely to impurities in kaolin aggregates.
Can 2 8.03%	Cryst. kaolinite	Quartz	Tourmaline		Pale olive buff tinge Pl. XL 21″′ f.	Coloring is due largely to impurities in kaolin aggregates.
Can 3 13.45%	Cryst. kaolinite		Quartz	Tourmaline Zircon	Pale olive buff tinge Pl. XL 21″′ f.	Coloring is due largely to impurities in kaolin aggregates.
Can 4 19.58%	Cryst. kaolinite			Quartz Tourmaline	Tilleul buff tinge Pl. XL 17″′ f.	Coloring is due largely to iron-stained kaolin.
Overflow 48.50%	Mostly cryst. kaolinite					

Discussion

H. RIES: I have read Mr. Schurecht's paper with great interest, the more so because in some work undertaken for the United States Geological Survey, we had a microscopic examination made of over 100 samples of clay, the results of which have already been published in condensed form.[1] In this work a study was made not only of the raw clay, but also samples fired to 1150°C and 1300°C.

Two minerals that were almost universally present were kaolinite and hydromica. The latter name was applied to certain distinctly micaceous grains, which showed single and double refraction higher than kaolinite, but not so high as muscovite or sericite. The degree of these refractions varied in the different clays, and it was assumed that there is an isomorphous graduation between sericite and kaolinite, with a gradual loss of potash and the addition of water, and that in weathering products such as these the hydromica represents a transition stage of weathering towards kaolinite as the final product.[2]

In the samples of white clay from Georgia which were examined it was noticed that on the average, kaolinite was usually abundant; hydromica, common; quartz, scarce; zircon and rutile, scarce.

The white clays from South Carolina showed kaolinite to be abundant; hydromica, common; quartz, variable; rutile, fairly common; zircon, scarce.

The white residual clays from the Saylorsburg district of Pennsylvania had kaolinite in abundance; hydromica in moderate to abundant quantity; quartz, common to abundant; rutile usually abundant; zircon, tourmaline, epidote and titanite, scarce.

Some rather interesting changes occurred in the firing. Thus at 1150°C the hydromica as shown by a study of thin sections either disappeared forming an isotropic mass, or else it lost the greater part of its interference color. The only exception was where the hydromica grains were much larger than usual, in which case it was noticed that the central portion of the grains retained the original interference color.

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[1] Somers, R. E., "Microscopic Examination of Clays," *Jour. Wash. Acad. Sci.*, **9**, 113 (1919).

[2] See also Calpin, S. L., "Studies of Flint Clays and Their Associates," *Trans. Amer. Ceram. Soc.*, **24**, 306 and 338; also Hickling, G., "China Clay. Its Nature and Origin," *Trans. Inst. Min. Engrs.*, **36**, 1908–1909; Also *Econ. Geol.*, **15**, 243 (1920).

Kaolinite when not fluxed, appeared to retain its shape or at least a good part of its interference color.

Tourmaline and probably epidote seemed to disappear at 1150°C but rutile, zircon, and probably titanite seemed unaffected even at 1300°C.

Sillimanite was identified in a Florida white clay fired at 1300°C and had apparently formed from large flakes of kaolinite and hydromica, as was indicated by composite flakes of sillimanite and one of the other two minerals.

It seems not unnatural, as mentioned by Mr. Schurecht, that the Georgia and South Carolina white clays should be fine-grained, and contain a larger quantity of colloidal matter, than the north Carolina kaolins since they have been more exposed to water action, and this fact has been previously emphasized by N. B. Davis.[1]

[1] "The Plasticity of Clay and Its Relation to Mode of Origin," *Trans. Amer. Inst. Min. Engrs.*, vol. II, p. 451, 1916.

Ceramic Experimental Station
U. S. Bureau of Mines
Columbus, Ohio

A LOW FIRE PORCELAIN[1]

By Charles F. Binns and Tina Burdick

ABSTRACT

Pieces of the following composition were cast and then fired at about cone 02, or lower, and then glazed and fired at cone 4. The result was a pleasing porcelain.

Frit Batch: Whiting, 0.32 × 100 = 32; Niter, 0.28 × 202 = 56.5; Borax, 0.12 × 328 = 45.8; Soda Ash, 0.18 × 106 = 19; Magnesite, 0.10 × 84 = 8.4; Calcined Clay, 0.24 × 222 = 53.3; Flint, 1.8 × 60 = 108; Total = 322. Georgia Clay 0.07 or 18 parts was added to the fritted batch.

The object of this study was to produce a porcelain at the temperature of cone 4, somewhat after the fashion of the French Pâte Tendre, but a once-fired ware.

The glaze was to be made without lead oxide. As there was no known mineral which would produce vitrification under this heat treatment it was decided that the body must contain a frit. It was thought possible that the glaze might be built upon the same frit.

The first frit made up corresponded to the following formula:

Na_2O	0.3	Al_2O_3	0.55	SiO_2	2.88
MgO	.4				
K_2O	.5				

In order to introduce the high content of alumina it was decided to use cryolite, Na_3AlF_6, which it was expected would reduce the solubility of the melted frit. The frit, as made, ran through the drop furnace fairly well but it was found that 9.6 percent was soluble in water. A change was therefore made as follows:

Formula of Second Frit

Na_2O	0.3	Al_2O_3	0.40	SiO_2	3.42
MgO	.5				
K_2O	.2				

This proved to be more satisfactory, the solubility being reduced to 4.2 percent.

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[1] Received Oct. 11, 1921.

The batch weights of frit are: cryolite 126, magnesite 42, feldspar 165, flint 90.

The feldspar used was rather impure, corresponding to the formula K_2O, 1.5 Al_2O_3, 9.6 SiO_2, with the weight of 825.

A diagram of twenty-one body mixtures was then made on the triaxial frame using the three following bodies as apices.

	No. 1	No. 2	No. 3
North Carolina Clay	10	40	..
English China Clay, MGR 1	10	..	40
Feldspar	20	10	20
Flint	30	30	30
Frit	..	20	10
Ball Clay J.P. 9	30	..	..

No body in the series was found to be satisfactory so that a new series was made as follows:

	No. 4	No. 5	No. 6
English China Clay, MGR 1	40	40	50
Feldspar	..	30	15
Flint	30	30	20
Frit	30	..	15

Numbers 4 and 6 offered desirable possibilities and a series of four was made between them.

	A	B	C	D
No. 4	0.8	0.6	0.4	0.2
No. 6	.2	.4	.6	.8

Body D proved to be fairly satisfactory and was found to contain: English china clay, MGR1 48, feldspar 12, flint 22, frit 18.

A batch of this mixture was made up and ground but upon casting the pieces they were found to be very brittle and difficult to handle. The mixture was therefore changed to: English china clay, MGR1 40, Georgia clay 6, feldspar 12, flint 20, frit 22.

Tests were made of this and it was found to work much better. The body was white and fine grained but it was still tender and had to be handled carefully.

The body was ground in a ball mill, the charge being 500 grams. It was ground in enough water to make it an easily flowing slip and was not washed when taken from the mill. It was kept in slip form at the consistency of a good casting slip and allowed to stand at least three days before using. Two-tenths of a gram of cobalt sulphate were added to one thousand grams of clay for a bleach.

Glaze tests were then made using the following two formulae and the body frit as the third member, the triaxial plot of twenty-one members being followed.

Glaze A

CaO	0.60	Al_2O_3	0.25	SiO_2	2.65
K_2O	.20	B_2O_3	.30		
Na_2O	.20				

Glaze B

CaO	0.40	Al_2O_3	0.25	SiO_2	2.65
K_2O	.30	B_2O_3	.30		
Na_2O	.30				

Glaze C (Body Frit)

Na_2O	.30	Al_2O_3	.40	SiO_2	3.42
MgO	.50				
K_2O	.20				

Clay to the amount of 0.07 was added in the mill. Glaze 17 contained 0.8 of B and 0.2 of C and proved to be the best.

Formula of Glaze 17

CaO	0.32	Al_2O_3	0.31		
K_2O	.28	B_2O_3	.24	SiO_2	2.42
Na_2O	.30				
MgO	.10				

Batch

Whiting	.32×100=32	Magnesite	.10× 84=8.4
Niter	.28×202=56.5	Calcined Clay	.24×222=53.3
Borax	.12×328=45.8	Flint	1.8 × 60=108
Soda Ash	.18×106=19	(Total)	322

Georgia clay 0.07 or 18 parts was added to the fritted batch.

It will be noted that the plan of using the body frit as a glaze basis was not carried through. The glazes which contained this frit were not good.

The pieces were cast and then fired at about cone 02 or lower to harden them. They were then glazed and fired at cone 4.

The result was a pleasing and even beautiful porcelain, having a good deal more of the true porcelain character than the early soft porcelains. Under-glaze colors were used with some success in decoration.

ALFRED UNIVERSITY
ALFRED, NEW YORK

THE DEGREE TO WHICH DIFFERENT GLAZE COMPOSITIONS TAKE VAPOR LUSTERS[1]

By R. T. Watkins

ABSTRACT

Glazes having an oxygen ratio of approximately 3 to 1, a medium or low acid content with a B_2O_3 to SiO_2 ratio of approximately 1 to 2.5 and high in lead and low in lime, take the best vapor luster effects.

Introduction

The iris or mother-of-pearl luster resembles, as the name indicates, the iridescence or play of colors observed in sea shells. The luster of pearls[2] is due to minute indulations of the edges of alternate layers of carbonate of lime and membrane, which impart a beautiful iridescent sheen, ranking pearls with the best of gems.

Mother-of-pearl iridescence[3] on glass ware and pottery is produced by providing one or more transparent to translucent thin layers of suitable composition over the surface of the glass or glaze. Light is reflected from both the upper and lower surfaces of such layers. Variations in thickness and successive layers are found most favorable for reflecting back certain colors and for cutting off other colors, especially complimentary colors. This gives a more or less regularly banded series of prismatic colors, while a layer of strictly uniform thickness gives a single uniform color.

Iridescent decorations on glassware[4] have been made for some time, but the process is accompanied by many difficulties when applied to pottery, as was formerly brought out by Weiskopf,[5] the first to make the process generally known. Weiskopf used

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[1] Received August 3, 1921. Published by permission of the Director U. S. Bureau of Mines.

[2] T. Wodiska, "Book of Precious Stones."

[3] Ashley, *Trans. Am. Ceram. Soc.*, **7** (1905).

[4] Ashley, *Ibid.*, **7** (1905).

[5] Wagner's *Jahresbericht* and Stohman Kerl's *Dictionary*.

the following mixture which he introduced into a muffle kiln containing the ware to be irised, the temperature being at a red heat: 1 part barium carbonate, 0.5 part strontium carbonate, 2.0 parts tin salt ($SnCl_4$). This mixture produces a vapor which when coming in contact with the ware, produces a mother-of-pearl effect, strontium giving red, barium blue and stannic chloride various colors.

The composition of the glaze has very much to do with the ability of the vapor luster to produce the iridescent effect, and for this reason the writer selected three different groups of glazes, each group having the following variations; (1) variation in oxygen ratio, OR; (2) variation in the B_2O_3 to SiO_2 ratio; (3) variation in the lime and lead content.

Preparation

The three groups chosen were:[1]

1.	Group I	O R	0 in acids	6
			0 in bases	1
2.	Group II	O R	0 in acids	4.5
			0 in bases	1
3.	Group III	O R	0 in acids	3
			0 in bases	1

These groups were chosen because they represent a considerable variation in SiO_2, B_2O_3, PbO and CaO contents. 0.2 equivalent Al_2O_3 was maintained constant in all the glazes of this study.

The following rules were observed in making up the frits: (1) All the RO was included; (2) all the Al_2O_3 except 0.05 equivalent; (3) all the SiO_2 except 0.4 equivalent. The frits were mixed thoroughly and melted in a gas fired crucible frit kiln. No difficulty was met with in melting them. They were wet ground, evaporated to dryness and passed through a 100 mesh screen. Blending was done dry. The test pieces used were biscuit whiteware tile.

[1] Whitmer, J. D., *Trans. Amer. Ceram. Soc.*, **11**, 262(1909). "A Study on the Production of Opalescence in Highly Acid Glazes." Groups 7, 4 & 1—for convenience will call 1, 2 and 3 in the following.

The glazes were applied to a thickness of about $^1/_{16}$ of an inch and fired to cone 10 in a gas fired test kiln.

Procedure in Irising

The glazed tile were placed in a small electric furnace near the top and heated to a temperature of 700°C. They were held there for $^1/_2$ hour, whereupon enough of the following mixture:

Barium Nitrate	2 parts
Strontium Nitrate	1 part
Stannic Chloride	3 parts
Bismuth Nitrate	0.5 part
Sulphur	1 part

was strewn upon the floor of the furnace to fill it with thick vapors. The furnace was then shut off and the contents allowed to cool. If the glazes become matt, it may be either due to too strong heating or to too much iris salts. Metallic specks are produced if the iris preparation is brought too near the object to be irised. Too weak a luster is produced, either if the objects are not hot enough or if iris salts are insufficient. Finally, an excess of bismuth nitrate in the mixture was found to blacken the objects, causing the mother-of-pearl effect to be obscured.

Results of Work

The results of the work are shown in detail in the charts (see Tables 1, 2 and 3). A few general deductions can be drawn from a study of the results. It is observed first, that those glazes which have a medium or low acid content can be given the best mother-of-pearl effects. Second, that high lead and low lime seem to be conducive to better results. Third, in glazes having a low acid content, a B_2O_3 to SiO_2 ratio of 1:2 and 1:2.5 gives the best effects.

GROUP I

$$O:R \begin{cases} \text{O in acids} \\ \text{O in bases} \end{cases} = \frac{6}{1} Al_2O_3 \text{ Eqv.} = 0.2$$

	R O Content				Series 1 Ratio 1:2		Series 2 Ratio 1:2.5		Series 3 Ratio 1:3		Series 4 Ratio 1:4		Series 5 Ratio 1:5	
	K_2O	Na_2O	CaO	PbO	B_2O_3	SiO_2	B_2O_3	SiO_2	B_2O_3	SiO_2	B_2O_3	SiO_2	B_2O_3	SiO_2
A	0.15	0.15	0.40	0.30	1.3714	2.7430	1.2000	3.000	1.0667	3.1830	0.8727	3.4908	0.7384	3.6922
					Poor		Poor		Fair		Poor		Fair	
B	.15	.15	.50	.20	.3714	2.7430	.2000	3.000	.0667	3.1830	.8727	3.4908	.7384	3.6922
					Poor		Fair		Poor		Poor		Poor	
C	.15	.15	.60	.10	.3714	2.7430	.2000	3.000	.0667	3.1830	.8727	3.4908	.7384	3.6922
					Poor		Poor		Poor		Poor		Poor	
D	.15	.15	.70	.0	.3714	2.7430	.2000	3.000	.0667	3.1830	.8727	3.4908	.7384	3.6922
					Fair		Poor		Poor		Fair		Poor	

TABLE 1

GROUP II

$$O:R \left\{ \begin{array}{l} \text{O in acids} \\ \text{O in bases} \end{array} \right. = \frac{4.5}{1} Al_2O_3 \text{ Eqv.} = 0.2$$

	R O Content				Series 1 Ratio 1:2		Series 2 Ratio 1:2.5		Series 3 Ratio 1:3		Series 4 Ratio 1:4		Series 5 Ratio 1:5	
	K_2O	Na_2O	CaO	PbO	B_2O_3	SiO_2	B_2O_3	SiO_2	B_2O_3	SiO_2	B_2O_3	SiO_2	B_2O_3	SiO_2
A	0.15	0.15	0.40	0.30	1.0286	2.0571	0.9000	2.250	0.8000	2.3915	0.6545	2.6182	0.5538	2.7692
					Good		Good		Poor		Fair		Poor	
B	.15	.15	.50	.20	.0286	2.0571	.9000	2.250	.8000	2.3915	.6545	2.6182	.5538	2.7692
					Poor		Good		Good		Fair		Poor	
C	.15	.15	.60	.10	.0286	2.0571	.9000	2.250	.8000	2.3915	.6545	2.6182	.5538	2.7692
					Poor		Poor		Good		Fair		Poor	
D	.15	.15	.70	.0	.0286	2.0571	.9000	2.250	.8000	2.3915	.6545	2.6182	.5538	2.7692
					Poor		Poor		Poor		Poor		Poor	

TABLE 2

GROUP III

$$O:R \left\{\begin{array}{l}\text{O in acids}\\ \\ \text{O in bases}\end{array}\right. = \frac{3}{1}Al_2O_3\text{ Eqv.} = 0.2$$

	R O Content				Series 1 Ratio 1:2		Series 2 Ratio 1:2.5		Series 3 Ratio 1:3		Series 4 Ratio 1:4		Series 5 Ratio 1:5	
	K_2O	Na_2O	CaO	PbO	B_2O_3	SiO_2	B_2O_3	SiO_2	B_2O_3	SiO_2	B_2O_3	SiO_2	B_2O_3	SiO_2
A	0.15	0.15	0.40	0.30	0.6857	1.3714	0.60	1.50	0.5333	1.60	0.4364	1.7456	0.3692	1.846
					Excellent		Excellent		Good		Good		Good	
B	.15	.15	.50	.20	.6857	.3714	.60	.50	.5333	.60	.4364	.7456	.3692	.846
					Excellent		Good		Good		Good		Fair	
C	.15	.15	.60	.10	.6857	.3714	.60	.50	.5333	.60	.4364	.7456	.3692	.846
					Good		Fair		Fair		Fair		Poor	
D	.15	.15	.70	.0	.6857	.3714	.60	.50	.5333	.60	.4364	.7456	.3692	.846
					Fair		Poor		Poor		Poor		Poor	

TABLE 3

A CONVENIENT INSTRUMENT FOR MAKING SHRINKAGE MEASUREMENTS[1]

By W. C. Broga and C. J. Hudson

ABSTRACT

See Figure 1.

A characteristic of most clays is a shrinkage which takes place when fired; a study of clays infers a study of shrinkages.

Convenient clay samples for shrinkage determinations can be made up in the shape of discs. By means of the instrument described in the following paragraphs, discs can be quickly and accurately measured both before firing and after, and the percentage shrinkage readily determined.

Figure 1 is a photograph of the instrument. It consists of an iron casting, A, upon which is mounted the disc B; the disc is attached to a small shaft running through its center and is mounted in a ball bearing. Attached to the periphery of the disc B is a rather stiff fine wire, C, which runs from B through the perforated guides D_1 and D_2, thence around the disc E, through the perforated guide D_3 and finally to the clamp F. By rotating the disc B in a clockwise direction the wire is brought tightly around the disc E; by a suitably attached pointer, G, a reading may be obtained on the scale at the extreme right. By stretching the wire tightly the disc E is always brought up against the stop H which should be so adjusted that the parts of the wire between D and F, except that which encircles the disc E, will be collinear. The instrument is mounted on legs at the back which give it an inclination of about forty-five degrees downward toward the operator. The weight of the pointer G keeps the wire taut.

The method of measurement is to first raise the pointer G, thus rotating the disc B in a counter-clockwise direction, loosening the wire C thereby enlarging the loop around E; while held in this position, a new disc is inserted in the wire loop, the pointer is allowed to drop, the wire is brought tightly around the new disc, and a reading made on the scale.

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[1] Received Oct. 13, 1921.

If the discs have been made in the same mold, presumably their prefired measurements will be alike and the pointer, by means of the adjusting screws I and clamp J, can be brought to read zero. The scale may be so graduated as to read centimeters of circumference shrinkage, or, as in the present case, it may be graduated to read directly in percentage of circumference shrinkage.

The instrument described is equipped with a number of small devices which add greatly to its usefulness. The arm K is actuated by a spring, thereby always insuring that the discs are against the stop H, or against the other stops indicated, if large discs are used. The dog L holds the pointer up while new discs are inserted into the wire loop. The arm K and the stops are grooved in such a way that as the wire loop is expanded, the wire is held in the grooves which guide it around the periphery of the newly inserted disc.

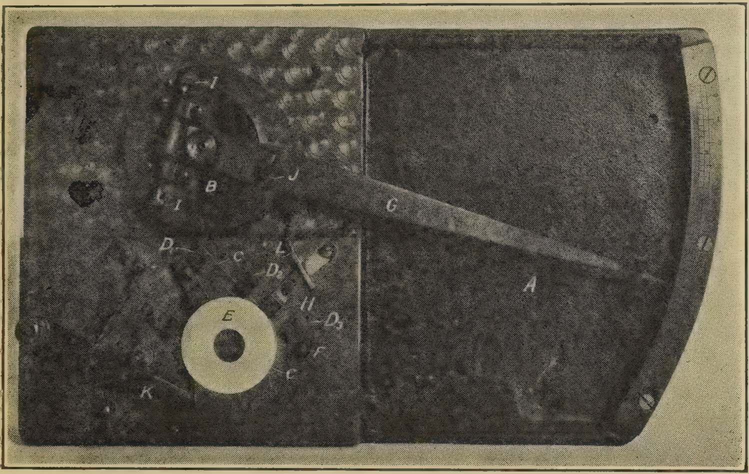

FIG. 1.

The construction and principle of operation are evident from figure 1.

Discs of the Veritas type may be used to good advantage in studying the heat distribution inside a kiln; a large number may be set with the ware without encroaching upon kiln space. After drawing, these discs can be measured, their shrinkages determined, and the relative heat distribution within the kiln studied. Where large numbers of discs are used for this purpose such an instrument greatly facilitates the measurements.

An instrument similar to the one described can be readily made in a small machine shop. Figure 1 is an illustration of the one in use at Norton Company. The main casting A is 10 × 17″ and from $^1/_8$″ to $^1/_4$″ thick; legs about 5″ long are attached to the back so as to give the main casting an inclination of about 45° toward the user. The disc B is 4″ in diameter and the pointer G is 12″ long, the length of the scale is about 8″. The wire used is made of stiff spring steel about 20 gauge. The instrument will measure discs up to 3″ in diameter.

Norton Company
Worcester, Mass.

OPERATION OF LEERS[1]

C. E. Frazier

ABSTRACT

The *muffle* and *open types of leers* are compared. The latter has the following advantages: (1) More uniform temps. in the annealing chamber; (2) prevents ingress of cold air beside pans and thus avoids consequent cracking of the ware; (3) better control of temp. and greater reliability of pyrometric indications; (4) less fuel per gross of ware.

Size of leers: Leers 8 ft. wide and 65 ft. from center to center of sprockets are recommended for the average glass.

Leer chains: Chains having a working strain of 5800 lbs. at 200 ft. per minute are recommended.

In the discussion, L. H. Adams points out that the *exact annealing schedule* required for any glass can be computed from the annealing constants of the glass which are known or can be determined in the laboratory.

The object of this discussion is to bring out the essential factors that enter into the proper annealing of glass articles rather than to discuss the technical side of the question, and in order to treat the matter intelligently, we must first determine the causes of annealing troubles.

The purpose of the leer is to remove the strains in glass articles which are necessarily introduced during the manufacturing operations. Since the plungers and the molds must be maintained at a temperature lower than that of the glass the conditions in the pressing operation are favorable for the production of strain and it is obvious that the greater the difference in temperature between the glass and the mold or the plunger, the greater will be the strain from this source. After removing from the mold the article is further chilled until it may be carried to the leer without distortion, but if this chilling is allowed to proceed too far, for example, through negligence of the carrying-in boy, the strains are unduly increased and the annealing is thereby made more difficult. The size, shape and weight of the article are

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[1] Received March 17, 1921.

also important factors which determine the quantity of the strain produced and which must be considered in the operation of the leer.

To remove these strains it is necesssary to raise the temperature of the article to a point which is higher than that at which the strains were created, and to maintain this temperature (soak) for a sufficient time to allow the glass to become thoroughly and uniformly heated. After this it must be cooled gradually to a temperature below which strains can not be introduced by rapid cooling. Experience has shown that the initial temperature of the annealing chamber should be from about 800°F to 1100°F (425°C to 595°C), and that the time necessary for "soaking" is from forty-five minutes to one hour twenty minutes, depending on the shape and weight of the article and on the method of manufacture. The exact conditions in the leer can be determined only by experience with the article to be annealed.

Even though the temperature and treatment in the hot end of the leer be correct, the ware may easily be destroyed by incorrect treatment as it passes through the leer. It is not uncommon to observe ware, which has been "melted down" in the hot end, coming through the leer in a broken condition. This indicates that the temperature of the hot end was high enough to remove the strains and that at some point after leaving the hot end, the article was cooled too rapidly. This may result from a draft of cold air or from cold pans. To eliminate these disturbing conditions in the open type of leer it has been customary to apply auxiliary heat underneath the pans, and while this method has improved annealing, it has been quite expensive from a fuel standpoint and at the same time has caused rapid depreciation of the pans. This heat under the pans serves another purpose than that mentioned above: it causes more uniform temperature in the annealing chamber and consequently results in better annealing.

To properly anneal any piece of glass, the following conditions are necessary: proper mold design, proper working temperatures, proper temperature in annealing chamber, proper "soaking" time, and gradual cooling of ware after it leaves the hot end of the leer. This latter condition is very necessary on any type of leer, whether open or muffled, continuous, or hand pulled pan type.

The muffled leer has many advantages over the open type, some of which are as follows: more uniform temperature in the annealing chamber, elimination of the cold air coming up by the side of or between the pans, better control of temperature, and greater capacity.

While a muffle leer will use more fuel than an open leer, it has been thoroughly demonstrated that the cost of fuel per gross of ware is less than with an open leer. Another feature that is of great importance in the packer's trade is that a muffle leer eliminates the necessity for the washing of the ware, when operated with raw producer gas. There are several designs of muffle leers on the market any of which will give better annealing than the open leer.

A very common trouble with the open leer is that the pyrometer couple is invariably placed in the center of the crown extending through the brickwork a few inches. It is a well known fact that in such a position the pyrometer will register a higher temperature than the temperature at the pans, and this difference is dependent entirely on the height of the crown and the kind of a flame employed. This temperature has been known to vary as much as 250° and it has been found that by changing the location of the couple so as to give a more nearly correct record of the temperature at the pans, breakage was practically overcome.

In one instance in the writer's experience, the pyrometer couple extended through the crown of the leer and the pyrometer indicated a temperature of 1200°F while the pan temperature was 800°F owing to the fact that the couple was so placed as to receive the direct heat from the flame. After changing the couple so that the pyrometer indicated the correct temperature, and increasing the temperature of the annealing chamber, the trouble was overcome.

Another experience worth mentioning was an investigation for the purpose of overcoming breakage on fruit jars which had stood what is known as the hot water test. It was proved that this trouble was caused by a drop of 200° to 250° in the first arch back of the fire box and it was entirely overcome by reducing this drop in temperature to about 75°. It has been found that the correct rate for cooling ware is obtained with a temperature drop of about 50° to 60° for every five feet after the ware leaves firebox until it reaches a temperature of about 350°F, after which time rapid cooling does not harm, and with some classes of ware rapid cooling from 500°F is permissible.

The correct length of the leer has been a matter of controversy for years. After a very careful study, it has been decided that 65 feet from center to center of sprockets is sufficient for the annealing of the average glass, although there are exceptions. In one installation a 65 foot leer was built along side of an 80 foot leer and after a year's operation on the same kind of ware, the owner cut fifteen feet from the 80 foot leer and purchased two more 65 foot leers which makes his equipment now stand four (4) 65 foot muffled leers.

Experiments have been made with leers 5, 6, 7, 8, 9, and 10 feet wide and it has been concluded that the 8 foot leer gives more real satisfaction than any other width. The reasons for this are as follows: It gives more uniform temperatures in the annealing chamber than wider leers, has more mechanical strength than wider leers and is also more flexible. It is needless to state that different shaped articles as well as articles of different weight require different treatment and it is therefore not advisable to attempt to anneal articles differing considerably in shape and weight together in the same leer. Experience has shown that three 7 foot leers are preferable to two 10 foot leers and four 8 foot leers are better than three 10 foot leers. The reason we recommend 8 foot leers is because an 8 foot leer costs very little more than a 7 foot leer and gives practically the same flexibility and uses no more fuel.

We had a client a little over a year ago who had installed three 5 foot hand pulled leers of the open type and had installed an automatic feeder which greatly increased his production. He wished to install a continuous leer but these could not be installed on account of the time limit. We therefore arranged to muffle his old leers to give him the capacity required while the new leers were being manufactured, and much to our surprise he annealed successfully in these 3 leers 400 gross of milk bottles in 24 hours and accomplished it more satisfactorily than he had been able to anneal 250 gross in the open leers.

Any of you who have had experience with continuous leers have no doubt had the annoyng experience of the leer chain pulling in two after the leers had been in use for a year or two. This results, first from side loading the chain, and second because the chain is too light for the work in question. After it has been subjected to the heat for some time it becomes too weak for the duty it has to perform and eventually breaks.

The chain used on the first continuous leers had a working strain of 2000 lbs. at 200 feet per minute; the next chain was of 2300 lbs. working strain at the same speed; and the next was a chain of 3600 lbs. at the same speed, but a change in design of the leer caused side loading on the chain, which, investigation proved, reduced the safe working strain by 50%. This meant, in effect, a weaker chain than the original and although the design was greatly improved, the chain was too weak to withstand the strains which caused the continual breaking of the chain. Chains now in use have a working strain of 5800 lbs. at 200 feet per minute and we have never heard of one pulling in two.

Discussion

By L. H. Adams.—This paper is an interesting account of some of the factors connected with glass-annealing, and such discussions as Mr. Frazier's are valuable aids in the design of leers.

It would seem, however, that in considering the principles underlying the annealing of glass, it is essential to take account of the physical nature of the annealing of glass. In the first place it is desirable to adopt some standard of annealing, that is, the maximum amount of strain (in definite units) that can be tolerated in the given class of ware. In the second place the problem of glass-annealing can be dealt with intelligently only by starting with the known (or determinable) annealing-constants of the particular kind of glass used. When the constants of the glass are known, it is a very simple matter to determine in advance exactly the temperature-cycle to be followed. The annealing-process naturally divides itself into two stages: first, the existing strain must be removed, and next, the glass must be cooled in such a way that the new strain introduced does not exceed the allowable limit. There are several ways by which this may be done. The glass may be heated to the temperature at which strain disappears almost instantaneously (about 550° C for ordinary soda-lime glass) and then cooled slowly. Or, on the other hand, the glass may be heated to a lower temperature for a longer time and then cooled at a much faster rate than by the first method. The second method is the better one for reasons which, for lack of space, it is not possible to enumerate at this time.

As indicated by Mr. Frazier, below a certain temperature the cooling may be much more rapid. This is true no matter what kind of a temperature cycle is used. Below about 400° for ordinary soda-lime glass and about 300° for lead glasses the permanent strain is not influenced by the speed at which the glass is cooled, and hence below these temperatures the cooling rate is limited mainly by what the glass will stand without breaking as it is cooled.

The calculation of the maximum cooling rate is one of the simplest of problems. The rate is inversely proportional to the square of the thickness and for a sheet of glass $^1/_2$ inch thick is 80°C per minute. In the later stages of the cooling, therefore, cooling may be *regular*, *i. e.*, it is not sufficient that the average rate be within the limit specified; the rate at any moment must be below the given amount.

Finally it should be noted that the statement "It is necessary to raise the temperature of the article to a point which is higher than that at which the strains were created" is meaningless for the reason that strain is not created at any particular temperature. Actually the strain makes its appearance at comparatively low temperatures, its amount being (mainly) determined, however, by the cooling rate of the glass at the higher temperatures, *i. e.*, by the rate throughout a certain range, which for ordinary soda-lime glasses is between 400° and 550°C.

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THE COST SYSTEM AS AN AID TO EFFICIENT PLANT CONTROL[1]

By Dwight T. Farnham

ABSTRACT

A cost system for a clay plant is described, by means of which complete records are kept of the condition of the plant each day as compared with an established standard. The results of such a system are a more perfect understanding between superintendent and general manager as to the actual factory conditions and increased efficiency in plant control. Graphic charts keep the information before the executives and workmen alike, thus leaving no one in ignorance of the progress of the work as compared with the established standard.

In the past too many cost systems have been devised by bookkeepers and not enough by executives. As a result the majority of cost systems provide for everything balancing to the third decimal place about seven weeks after the history of events, which the figures record, began to happen. Usually about the twenty-first of February the General Manager receives "news" as to what happened January first. Under the circumstances we can not blame him for being bored and throwing the carefully prepared figures aside for a trip through the works.

The trip through the works is quite as unsatisfactory a method of controlling the efficiency of operation as the cost system. There is too much element of chance about what is encountered. Some superintendents are born lucky and always throw the last of a bad kiln over the dump just as the General Manager arrives. Others are less fortunate and the sight of fourteen men drawing a kiln with post-mauls and steel crow bars is always a sure sign that the General Manager has just entered the front gate.

Furthermore a good many superintendents have learned to be "tactful." Bitter experience has shown them that under the usual methods of works control they are judged by the front they put up. They therefore combine with a study of the boss'

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[1] Received March 10, 1921.

likes and dislikes a specious optimism and lead the weekly executive procession from point to point of safe interest, with all the enthusiasm and mendacity displayed by the professional guide in Rome or Naples. And the General Manager is usually about as helpless as the average American tourist under the same circumstances.

It may be that the incompetent or dishonest superintendent is eventually separated from the field of his endeavors by the evidence which accumulates against him on the cost sheet. But under the historical method there is too much opportunity for loss before the fire department is notified. Furthermore after seven weeks the evidence in the case is so scattered to the four winds that the opportunity to profit by an expensive lesson is lost. And finally with such scraps of evidence as exist, all in the hands of the defendants, it is not surprising if they find occasional alibis easier than continuous, efficient plant operation.

Just as long as General Managers are content to manage their properties by basing their decisions upon opinion rather than upon fact, just so long will incompetent factory executives continue to "get by." And it is more the fault of the Manager than of the superintendents and foremen. If no one has taught you how to collect facts or how to draw the correct inference from such facts, and if the management has refused to spend any money for the collection of such facts as you have timidly suggested might be valuable, you can not be blamed if you meet such crises as arise with "facts" manufactured upon the spur of the moment. Furthermore, if you have been expected to know what is going on inside a kiln instinctively and to remember what went on inside some forty other kilns at each stage of each burn and to compare the results in each case with the causes which produced them in such a way as to profit by spoiled kilns and to reproduce every exceptionally fine burn during the past year—you have not much respect for the manager who thought he could get that sort of a brain for a hundred and fifty dollars a month and you conclude that what he does not know will not hurt you.

The remedy is of course the collection of facts in the form of immediate, adequate and accurate records and a cost system either devised, or criticised in detail, by an executive of actual experience in the details of manufacture. I know of one case where a well known public accountant worked out a uniform cost system for a branch of the clay industry and proposed saving clerical work by counting only the spoiled ware which came from the kilns! This was not only bad accounting but bad psychology. He provided no check on the setting reports,—he was asking the kiln crew to tell on themselves whenever they smashed anything—and the factory foreman in charge of the crew to hang himself if he were incompetent. In as much as such crews—both drawing and setting—are paid mostly on a piece work basis, by failing to provide a check on the amount set, he was just begging the men to sweeten their tally sheets and so secure some easy money at the company's expense.

To operate a clay plant at all effectively the superintendent and the General Manager should have at least the following records daily—

1. Output from the machines and moulders in tons or thousands as compared to standard output.
2. Quantity. Set and drawn as compared to standard.
3. Quantity. Shipped.
4. Percentage of first quality, seconds and lost ware drawn from each kiln with detailed explanation of causes when firsts fall below an established standard.
5. Drier loss in percentage of output, by products.
6. Number of men at work in each department and the total tons produced per man per day.
7. Efficiency of operation of each department expressed in terms of a definite percentage of actual accomplishment to realizable standards set.
8. Coal and clay on hand as compared with a minimum standard set. (Careful inventory not required unless supply falls below standard.)
9. Machine shut-downs by departments in terms of percentages of possible running time.

This infomation should be entered on graphic charts in the factory control office in such a way as to make what is accomplished each day comparable with past performances and with standards. Past performances may be carried in the form of monthly averages and a cumulative curve should be carried showing the effect of each day's performance on the month to date.

For the use of the burners very complete records should be maintained in comparable form showing the progress of each burn and the results obtained.

Where the workmen in the various departments are paid in proportion to results obtained—which implies both quantity and quality of production—records of how nearly they approach standard earnings should be kept in such a way that men who are not regularly earning standard wages may be helped to do so.

These records as outlined require the establishment of standards of production. If this has not been done, the daily study of what is happening from day to day is alone of considerable value. However—if you do not know what you *ought* to be able to do, it is difficult for you—or anyone else—to judge how well you *are* doing.

From these reports monthly records and charts should be prepared and placed in binders upon the desks of the Superintendent and of the General Manager.

The actual production costs are of course prepared only once a month but it is comparatively easy to have the factory costs ready within two days of the close of the month, since the cumulatives referred to, provide for the gathering of the production data as the month progresses and a properly designed distributon sheet provides for the money distributed against the various products manufactured each day in each department being checked daily against the pay roll. As a result it is only necessary on February 1st to add in the distribution for January 31st and you are ready to divide the dollars by the quantities. The same plan followed in regard to supplies and raw materials makes it possible to have the operating costs ready for a conference between the Superintendent and his department heads on the second, and a written report to the General Manager in which exceptional conditions, either good or bad are explained, on the third. Factory costs then average two weeks old instead of three and a half weeks as is the case when they do not appear until the 21st of the month.

This course of procedure is comparatively easy for the Superintendent who is amply provided at all times with dependable facts and it takes up very little of the General Manager's time as compared with the old system. It promotes confidence on the part of both—since the Superintendent knows he is going to stand or fall upon a basis of what he *does*—instead of upon what he *says*—and the Manager knows he is getting the truth. Difficulties can be studied in the light of all the evidence while it is still hot and plans worked out to avoid a good many of these difficulties in the future. The whole organization is provided with the data necessary for intelligent decision and knows that whatever it does will be reflected in hard cold figures placed where everybody can see them. And there is no greater incentive to efficiency than the knowledge that you are to be rewarded exactly in proportion to your just deserts.

POROSITY: V. RECOMMENDED PROCEDURES FOR DETERMINING POROSITY BY METHODS OF ABSORPTION

By Edward W. Washburn and Elmer N. Bunting

ABSTRACT

Detailed Procedure.—For shaped test pieces details of the procedure are given under the headings, "Preparation of Test Piece," "Determination of Dry Weight," "The Absorption Apparatus," "Preparation of Standard Vaseline," "Saturation Procedure," "Calculation," and "True Density."

A Pycnometer Method.—A new and accurate method, which is applicable equally to shaped test pieces or to granular material, is described. Among other advantages it gives the operator control over the max. size opening which he desires to class as part of the pore space. It also can be made to indicate directly the necessary soaking period.

XIII. Preparation of the Test Piece and Determination of Its Dry Weight

43. Cleaning the Surface.—After the test piece has cooled to room temperature, its surface should be cleaned and smoothed and sharp corners and edges rounded as far as possible. Surface defects likely to conceal cavities should be opened with a knife or file so that the absorption liquid may be removed therefrom readily. In cleaning and smoothing the surface, the instruments and means employed will vary with the nature of the body. A stiff brush, a file, a sharp knife, a grindstone, sandpaper, etc., will all be found useful in different cases. The best one to employ in a given case must be left to the judgment of the individual. Obviously the method employed must not contaminate the test piece by filling its surface pores with any foreign material, nor must these surface pores be left filled with dust from the body itself. In the case of very soft, very porous bodies, a blast of air or a strong suction may be employed to advantage for freeing the body from dust. A final brushing of the surface with a good stiff brush may be recommended for most cases. If the surface of the test piece is covered with a hard glassy skin, one or, better, both ends of the piece should be cut or broken off so as to expose an interior surface. With highly vitrified bodies it is frequently necessary to remove the total surface layer in order to obtain the correct porosity values for the body itself.

44. The Dry Weight.—Transfer the clean test piece to a desiccator and allow it to stand over 95 percent sulphuric acid until it has attained constant weight, W_d. The time required for this may be materially hastened by evacuating the desiccator. In any case a few hours will suffice.

XIV. Saturation of the Test Piece

45. The Absorption Apparatus.—Figure 5 shows a convenient type of absorption apparatus. The absorption vessel V may be made of a heat resisting glass with the cover ground to fit the flange F, or of metal and a gasket used on this flange. If constructed of glass, the vessel should be round-bottomed and supported on legs, or in a base as shown. An ordinary round-bottomed glass flask may be substituted for the vessel V if desired, provided its neck is wide enough to admit the test pieces.

The tube A connecting the vessel V with the flask D should be an all-glass connection, if the absorption liquid is something which attacks rubber (*e. g.*, benzene or kerosene); otherwise, a flexible rubber connection may be used. All ground-glass joints and stop-cocks should be accurately ground and well lubricated. A good lubricant for this purpose may be prepared by heating together pure rubber, vaseline, and paraffine in any proportions between 7–3–1 and 16–8–1. A sealing varnish, which can afterward be readily removed with a cloth moistened with ether, is made by melting together equal parts of beeswax and rosin. It is applied hot, with the aid of a small camels' hair brush, to any point where a leak is feared.

46. Preparation of Standard Vaseline.—Melt a considerable quantity of vaseline, filter to remove solid particles, and transfer to a vessel which can be heated and evacuated. Boil the vaseline *in vacuo* for six hours, and allow it to cool completely in the vacuum. Store in a dust-tight container.

Determine its specific gravity at the average and at the minimum and maximum room temperatures by proceeding exactly as described in Sec. 47 below, but with a calibrated specific gravity bottle substituted for the test pieces.

47. Saturation Procedure.—(1) Place the test pieces in the absorption vessel, put on the cover, and see that all joints are tight.

(2) Place enough of the saturating liquid in the flask D to fill the absorption vessel V well above the level of the test pieces.

(3) Insert the stoppers R and R′, close cock S_2 and open cock S_3.

(4) Connect C with the vacuum pump and evacuate until air ceases to be given off from the liquid in D. The liquid may be boiled to advantage for a few minutes, being heated if necessary.

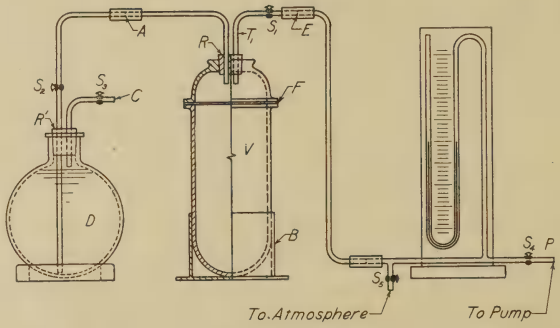

FIG. 5.—Apparatus for determining porosity by the vacuum saturation method.

(5) Close cock S_3, disconnect the pump from C and connect it to P.

(6) Open cock S_4, close S_5, and evacuate the absorption vessel until the manometer ceases to fall.

(7) Open S_2 and then S_3 *slightly* until the liquid in D rises and *just* fills cock S_2. Then immediately close S_2 and S_3 and continue the evacuation of V until, on closing S_4, the manometer shows a constant reading. This reading should be less than AB where B is the barometric pressure (in the same units as the manometer scale) and A is the fractional accuracy desired in the porosity.[35] If the pump employed will not give this degree of vacuum, then procedure 8*a* must be introduced.

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[35] See Sec. 28 above.

(8) With S_4 closed, stop the pump, open S_2 and then S_3 until enough liquid has been forced into V to completely cover the test pieces. If the absorption liquid is too stiff to flow readily at room temperature, the flask D and the vessel V may be kept in a pan of hot water.

(8*a*) If the vacuum pump gives a vacuum better than AB, omit 8*a* and proceed directly to 9; otherwise, proceed as follows, if the absorption liquid is a pure liquid: With the pump running, S_2 closed and S_4 open, warm the liquid in V until it *boils*. Continue the boiling until the air has been completely removed from the pores. The boiling period necessary to accomplish this will vary with the nature of the ware, and must be ascertained by experiment. This may be done by returning the test piece to the absorption vessel after its saturated weight has been taken and repeating the boiling-*in-vacuo* treatment to see whether a gain in weight takes place.

(9) With S_2 closed, open S_5 thus breaking the vacuum. Allow the test pieces to soak for at least S minutes, S being given by the expression

$$S = \frac{S_o}{z/z_o} \qquad (7)$$

where z/z_o is the relative penetrativity of the liquid at the soaking temperature employed, and S_o is, for the test pieces employed, the standard soaking period for water at 20°C. Values of $\frac{z}{z_o}$, for vaseline, at any temperature between 100° and 200°C may be computed from the relation

$$\left(\frac{z}{z_o}\right)^{1/2} = \frac{t-30}{480} \qquad (8)$$

If the necessary soaking period for water is not known, an approximate calculation of a minimum S may be made from the relation

$$S = \frac{l^2}{rz} \qquad (9)$$

where l is the maximum linear dimension of the test piece and r is the radius of the smallest pore which it is desired to fill. Values of z for vaseline may be taken from equation 5. This calculation, however, gives only a value for S above which the actual minimum soaking time must lie.[36]

(10) When the soaking has been completed and the contents of V are at room temperature, remove the test pieces, one at a time, wipe with a cloth dampened with the absorption liquid, and weigh rapidly, W_s. If vaseline is employed, the test pieces may be scraped with a spatula and then wiped with a piece of chamois skin or other similar material.

Care should be taken not to warm the test pieces by contact with the hands. A weighing tube may be employed, if desired, to avoid vaporization losses during weighing.

(11) Suspend each test piece from a fine wire and weigh it (W_h) suspended in water (or any other suitable liquid) whose density at room temperature is D_w, the specific gravity of the absorption liquid at the same temperature being D_s.

$$\text{Percent porosity} = x = \frac{100\ (W_s - W_d)D_w}{(W_s - W_h)D_s} \qquad (10)$$

$$\text{Bulk density} = D_B = \frac{W_d\ D_w}{(W_s - W_h)} \qquad (11)$$

48. Determination of the True Density.—This determination can be most conveniently carried out on a separate sample of the material, but if it is desired to use the test piece employed in the porosity measurements, the saturation liquid must first be removed from its pores. With water or other pure liquid, this should be effected by low temperature drying *in vacuo*, followed, if desired, by a short calcination at a temperature considerably lower than that at which the test piece was drawn in its previous firing.

If vaseline has been employed as the saturation liquid, the test piece should be crushed, the vaseline removed by washing with benzene or gasoline and then with naptha, and the material dried as above.

The dried test piece is then powdered and the true density determined in the usual way.

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[36] See Secs. 29 and 30 above.

XV. A Pycnometer Method for Determining Porosity by Absorption

49. Purpose of the Method.—The method discussed in the next few sections differs from those previously considered in that it is applicable equally to test pieces of standard shapes and dimensions and to irregular pieces or granular material. It has the further advantage that the operator may fix the dimension, dividing a pore from a hole or crack, at any size which he desires. The maximum surface-pore dimension is thus under complete control. The procedure involves a determination of the bulk density followed by a saturation experiment.

50. Procedure for Bulk Density.—A pycnometer of weight, W_P grams, capacity, V_P cc. (at the "setting" temperature), and having a form pequivalent to that shown in Fig. 6 is employed.

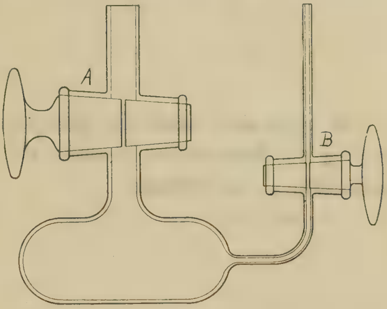

FIG. 6.—Combined volumeter and absorption apparatus for measuring the porosity of granular materials.

(1) Fill the bulb of the pycnometer with a coarsely granular, sieved, and dried sample of the material and weigh, W_1.

(2) Evacuate the apparatus through A until the pressure falls to less than $\frac{ABV_B}{V_P}$, where B is the barometric pressure, A is the fractional accuracy desired in the result, and V_B is the bulk volume of the sample of material.

(3) Admit mercury through B until the apparatus is full and the mercury level in A is some distance above the stop-cock.

(4) Close B and adjust the vacuum until, at room temperature, the manometer reading plus the distance h (from the center of the bulb to the mercury level in A) is equal to $0.05/d$ cm., where d is the diameter in cm. of the largest opening which it is desired to class as a *pore*, all larger openings being classed as *holes* or cracks.

(5) Close stop-cock A, disconnect the pump, and remove all mercury from above both stop-cocks. Then open A or B and weigh the pycnometer and its contents, W_2.

(6) Calculate the bulk density D_B of the material.

$$D_B = \frac{(W_1 - W_P)\ D_M}{D_M\ V_P - W_2 + W_1} \tag{12}$$

where D_M is the density of mercury at the temperature of operation 4.

51. Saturation Procedure.—(7) Remove the contents of the pycnometer, separate the sample of material from the mercury, *completely*, and return it to the pycnometer; or, if desired, take a new sample of the material for this determination. Weigh the pycnometer with the sample W'_1.

(8) Evacuate the apparatus until the pressure is not greater than AB where B is the barometric pressure and A is the fractional error permissible in the result.

(9) Admit the absorption liquid until the apparatus is full. Water may be used for this liquid, if it is without action upon the material, otherwise carbon tetrachloride, benzene or any other suitable *pure* organic liquid may be employed.

(10) With stop-cock A closed and B open, allow the apparatus to stand at room temperature, $t'°$, for the necessary soaking period. Then close B, remove all excess liquid from above both stop-cocks, and weigh, W'_2.

(11) Calculate the percent porosity.

$$\text{Percent porosity} = x = 100\ [1 - \frac{(D_L V_P - W'_2 + W'_1) D_B}{D_L\ (W'_1 - W_P)} \tag{13}$$

where D_L is the density of the absorption liquid at the temperature $t'°$.

52. Theory of the Method.—One obvious advantage of the pycnometer method is the approximately quantitative control which it gives over the size of surface opening which is to be classed as pore space. The pressure necessary to force mercury into a pore opening of diameter d, is equal to $\frac{4\gamma \cos\theta}{d}$ where γ

is the surface tension and θ the angle of contact. For mercury, $\gamma \cos \theta$ may be taken as 165 dyne/cm. at room temperature and hence the above expression is equal to $\frac{0.05}{d}$ cm. of Hg, where d is expressed in cm.

Thus for example, if we wish to class as *holes* or *cracks*, all openings larger than 0.1 mm., and as pores, all openings smaller than this, then the pressure in the pycnometer at the time of closing stop-cock B in operation (5) above should be $\frac{0.05}{0.01} = 5.0$ cm. of Hg. The value of d which is chosen will be determined by the character of the material and the purpose of the porosity determination, but an important feature of the pycnometer method is that this quantity is under experimental control.

In using the pycnometer method it is essential that the pieces of the sample employed should be approximately uniform in size and should not be too small, otherwise some of the space between particles would not be filled by the mercury and the result obtained would represent the porosity of the mass of material in the pycnometer rather than that of the body represented by the sample. The *minimum* allowable size is determined somewhat by the value chosen for d, the maximum pore diameter. The *maximum* size for the pieces of the sample is evidently determined only by the size of the neck of the pycnometer.

Owing to the fact that in operation (4) the apparatus functions as a rather sensitive thermometer it is evidently very easy to ascertain when temperature equilibrium has been attained.

For a similar reason operation (10) indicates the necessary soaking period which should be allowed, that is, the soaking period may be assumed to be over as soon as the meniscus in the small tube is falling at a negligibly small rate.

It is also evident that by graduating the small tube above stop-cock B it is possible to obtain considerable information about the character of the pores present in the material. Indeed, by controlling the pressure under which the liquid enters the pores of the material, one may determine the total pore volume of those pores having effective diameters between any two stated limits, and may thus classify the total porosity into groups of given pore size, and may determine what fraction of the total belongs within each class. Such a study could, however, best be carried out with mercury, the method being a static one.[37] For the smallest pores high pressures would, of course, be required.

(To be continued)

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[37] See Washburn, E. W., "Note on a Method of Determining the Distribution of Pore Sizes in a Porous Material.," *Proc. Nat. Acad. Sci.*, **7**, 115 (1921).

JOURNAL

OF THE

AMERICAN CERAMIC SOCIETY

A monthly Journal devoted to the arts and sciences related to the silicate industries.

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EDITORIALS

THE ART DIVISION OF THE AMERICAN CERAMIC SOCIETY

AN OUTLINE OF ITS ACTIVITIES: PRESENT PROGRAM AND FUTURE POSSIBILITIES

The Art Division, as its name implies is that Branch of the American Ceramic Society which devotes its activities and researches in the interest of the development of the artistic and decorative fields of ceramic work.

What These Activities Include.—Broadly speaking these activities include discussions, investigations and researches in connection with shape construction, ceramic draughtsmanship, design, decoration, modeling, ceramic sculpture, individual and commerical decorative processes, and the standardization of these in connection with the various types of ceramic wares. For instance, the technique and practical knowledge essential to whiteware practice is altogether different from that required in the manufacture of tile and architectural faience; and in connection with the various decorative processes, the successful execution of works in overglaze, underglaze on the clay or biscuit, stained clays and glazes, and with the mechanical processes, the problems surrounding each one of these are not only widely different in character, but they require a different technique and type of decoration.

The Relation of the Art Division to the Remainder of the A. C. S.—The Art Division is *not* a detached activity consisting of professional ceramic artists and decorators possessing little or no sympathy with allied technical and practical developments. As implied above, the active field is quite large, and it concerns not only the art worker, but the manufacturer and capitalist, the technical man, the practical potter, and finally the general public. Until the war period, ceramic developments in this country had not progressed on the same scale and with the same results as those of other countries. Our decorated wares with few exceptions could not compete with the productions of Europe and Japan. The artist and pottery decorator was merely a bench workman, and one of the lowest paid on the factory payroll. There was little or no competition with foreign concerns in those lines outside the general utilitarian wares made in the Trenton and East Liverpool districts. Consequently, except in those instances where definite technical requirements were essential to the successful marketing of the product (as is the case with chemical and electrical porcelain) there was no forced incentive to give serious consideration to those problems concerned with artistic excellence. But since the war the European and Asiatic countries have noted the potentialities of the American market to the extent that they are making strenuous efforts to capture this.

The foreign potter at present enjoys many advantages which we do not possess. Aside from traditional advantages, he is receiving valuable support from his respective government. He gives great attention to skill in potting. The foreign unions do not dominate labor to the extent that superior workmanship and facile production is discouraged. We do not have child labor in our potteries, and our scale of wages is much higher than is prevalent abroad. But one of the most vital conditions which the foreigner develops to the utmost extent and which we have to date not fully recognized is that concerned with artistic quality. The foreigner has government art and industrial schools. The young ceramic artist, designer and modeler must attend these schools in addition to serving his apprenticeship in the factories. The manufacturer himself is intensely interested in the schools, and in the decorative branches of his factories. He realizes that in many cases it is the decoration that determines the sale of his product. The question of price is obviously a determining factor as is evidenced by our interest in the American Valuation Plan. But the American Valuation Plan alone, desirable as it is, will not give us the dominant position we should enjoy in our own country if our product is not as fine in quality, or as beautiful as the importations of our foreign competitors. It is the purpose of the Art Division with what help and influence it can obtain from the manufacturer and every other interest concerned, to work for conditions which will result in a better understanding of what is involved in the production of wares needing the services of the artist and craftsman, and to assist wherever it can to raise the standard of excellence.

The Present Personnel of the Art Division.—Of the charter members of this division, twelve are manufacturers and general managers of clayworking plants, nine are artists or decorators, nine are ceramic instructors, five are potters, and three are dealers in ceramic supplies. Since the division was formed practically every member of the A. C. S. who is engaged in ceramic art work is a member of the Art Division.

The Art Division has the interest and active support of the Organizing Secretary and the "Old Guard," including the progressive element in the parent organization. In fact, the organization of this division would have been impossible without this.

What the Art Division Has Done during the First Year of Its Existence.—1. Submitted outlines on organization and development in relation to art activities. The paper by Mr. L. V. Solon dealing with glaze and color development for decorative work is a most valuable contribution vitally concerning the technical man as well as the ceramic artist. The question of suitability and standardization of the ceramic color palette is a problem that varies according to the conditions involved, but it is a problem which must be solved if we are to obtain satisfactory results; and this is only one of many developments which cannot be attacked unless the technical man and the artist work together.

2. The officers of the division have inaugurated their membership campaign, and have compiled a list of over two thousand

names of prospective members. This list is not nearly complete but it embraces the names of individuals in the industrial and educational ceramic fields.

3. In addition to the usual organization communications, over one thousand letters and reports on Art Division activities have been sent out at no expense to the parent organization. These communications consist of letters to officials of other organizations in the interest of industrial schools, questionnaires, membership campaigns, letters to officials of the A. C. S. on reorganization matters, exibitions, etc.

4. The Art Division has advocated and succeeded in getting the Society to adopt the policy of holding exhibitions of ceramic work at the annual conventions and also at the Chemical Exposition in New York. This is an important innovation, and one that will do much to increase the influence of the Society.

5. In connection with the Society publication *The Journal* the Art Division is advocating a type of publication which will include matter of interest to the practical potter, decorator and student in ceramics.

The Present Program of the Art Division.—1. *The development activity* which most concerns not only the Art Division, but all those interested in the ceramic industry is the establishment of government industrial schools. The American Ceramic Society through the Art and Whiteware Divisions must exert every ininfluence to establish suitable schools in localities most in need of these. The only logical way to assist in bringing about such a condition is to formulate a tentative program covering such matters as organization, essential personnel, curriculum, locality, equipment and cost involved. and to present such data to the officials of the Society for further recommendations, and then to enlist the active interest of such bodies as the U. S. Potters' Association, the Associated Tile Manufacturers, the terra-cotta group, the various manufacturers outside these organizations, and the local bodies—the chambers of commerce and educational boards and every other means to attain the degree of publicity which will lead to direct action. The establishment of industrial art schools in districts like Zanesville, East Liverpool, Wheeling and other pottery centers will be a long step toward the realization of a

National Science and Art Department at least the equivalent of those functioning in the countries of our commercial rivals. The Art Division is working unceasingly to assist in bringing such a condition about.

2. *Research work in ceramic draughtsmanship*, ceramic shape construction, including working drawings for models, blocks and cases, and molds. Practically no attention is given to these activities, yet a reasonable amount of applied practical knowledge will result in vastly increased efficiency, a great saving in plaster and clay material, and better potting with decreased loss.

3. *Outlines for research work in mechanical and manual decorative processes.* The condition of "secrecy" which for so long surrounded the technical and practical potter still exists with the decorator. Many decorative specialists engaged in this country retain control of formulas and processes, many of which are not only old fashioned and obsolete, but which could be used to a desired degree of efficiency if these were properly chartered and subjected to competent direction and supervision.

It is part of the Art Division program to classify those decorative processes in present commercial use, giving formulas and methods, accompanied with illustrations of types in the various stages. This will eventually result in the standardization of the most generally used processes and open the field to many high class decorative artists who have heretofore been barred because of their lack of knowledge of the practical part of the work.

4. *Outlines for research work in the field of ceramic instruction.* Considerable work has already been done in connection with formulating practical courses suitable for school work. The result of this will be published in *The Journal* in the near future. Many educational forces are interested in the possibilities involved in ceramic art instruction, but too little is known of the requirements. It is part of the program of the Art Division to not only coöperate with those schools needing information and assistance, but to standardize those processes which are suitable for school work.

5. *Exhibitions and publicity.* The general public and even the artist himself is not so concerned about the technique and exposition and discussion of methods as he is about the finished result. No artist would gain a reputation by simply writing and talking

about his work. He must exhibit it. The same conditions govern any industrial activity and particularly that of the ceramist. As a national organization, attempting to cover the entire industrial and educational fields we would be seriously limiting our possibilities of expansion and consequent influence if we neglected the opportunity to exhibit ceramic wares either as concrete examples of some specific development or in connection with some standard of properties, quality, or production method. We would become an introverted organization possessing no interest to many allied activities. The exhibits at the annual conventions could properly be chiefly technical in character, but when the A. C. S. is represented in national expositions and exhibitions the exhibit should surely be as comprehensive as space will allow. Our organizationhas an opportunity to exhibit American ceramic works afforded by no other group of interests. Everyone familiar with national and international expositions knows the time and labor involved in visiting the various ceramic displays. The A. C. S. is in a position to arrange an exhibit which will include practically every type of product made in the country. The value of such an exhibit both to the ceramic student and to the potter is obvious and needs no further comment here. The Art Division is cooperating with the other divisions in the interest of such exhibitions. The A. C. S. will have exhibits at the coming convention in February and at the Chemical Exposition in New York in September. When the benefits derived from such action are definitely recognized steps will be taken to establish a permanent exhibit or museum in the headquarters of the society. This will afford the scientist, the practical potter and student opportunity to examine actual examples of every type of ceramic work.

6. *A. C. S. interest in American museums.* Everyone interested in historical pottery is aware of the fact that no technical or practical information is offered by museum authorities, or that no such information accompanies the historical data usually attached to each exhibit; nor is it published by the museum authorities in separate form. Yet such information contributed by authoritative sources would be of unquestioned value to the industrial concerns interested in such types. While it would no doubt be a difficult matter for an individual to be instrumental in cre-

ating such a condition, it is easily possible that the A. C. S. might be the determining factor which would result in the compilation of a technical catalogue for one of the larger museums. If such a course were followed there is little doubt that the other museums would adopt this practice. Incidentally, the museum authorities would be quick to see that this would lead to a greatly increased interest in the exhibits. The Art Division is taking steps to approach certain of the museums with a view of ascertaining the probability of undertaking such a work.

Advantages of Membership in the Art Division.—1. *The manufacturer will be in a much better position to standardize his decorative processes than he is at present.* He will be able to keep in close touch with current developments in ceramic decorations. He will be able to organize his decorative and practical research department on a practical paying basis; an activity which will be much more productive and much less expensive than the present prevalent nondescript experimenting by people who are not equipped either by training or experience to do research work.

2. *With the existence of a definite research and development program* suitable to the particular needs of the plant, the executives concerned will be relieved of spasmodic participation in experiments, a condition which will allow them to concentrate on routine productive work. By being members of the Art Division they will be acquainted with particulars and conditions involved in new developments, and they will in consequence be better equipped to take care of regular factory production.

3. *Dealers.* In connection with desirable specifications and satisfactory standards, the dealer is more competent to judge ceramic wares if he knows of what these specifications and standards consist. His interest in the Art Division would hasten a condition where these standards could be established and maintained.

4. *Architects.* The advantages of a membership to this class are much the same as those offered to dealers. Every architect interested in tile and terra cotta should be familiar with the practical possibilities and limitations of these products. Both from a decorative and a structural point of view, there is much information in connection with standards which can be obtained if enough interest and support is active in the Society.

5. *Technical men.* Every technical man employed by a concern producing artistic wares should know something of the processes in practice and under development. The article by Mr. Solon previously referred to is one contribution which closely concerns the coöperation necessary between the various activities. The technical man cannot work alone, neither can the artist, and none but the decorative specialist can judge of the artistic qualities of color and texture, or of the suitability of a particular process to a particular type of decoration. This does not mean that the decorator is likely to encroach in the legitimate activities of the technical man. It means that the work of the technician will be put to proper use and developed to the fullest extent. The Art Division has much to offer to the technical man who has the vision to see that the result of his labor is not adequately presented unless it is done with the recognition that it must meet the conditions essential to good decorative quality, and that he must work in harmony with the artist.

6. *The designer and decorator.* To the greatest extent the success of the Art Division depends upon the interest and coöperation of the decorative specialist. It is fortunate that the rapidly increasing requirements of the present day commercial market demand considerably more artistic knowledge and skill than has been prevalent or acceptable to this time. These market demands will be met irrespective of the attitude of the incompetent decorator, the bench hack, or the reactionary. Happily there is no dearth of talent in other decorative fields, and with the increasing possibilities and needs in ceramic work, this talent will be used, in fact is already being used to assist in the manufacture of higher types of artistic productions. As is the case with every other industrial activity the artist and decorator must keep step with the march of progress, or they must make room for those who are better prepared. The Art Division has not been formed for the exclusive benefit of the decorator. As stated, it is an industrial activity to function in the interest of the development of ceramic art. It is practically essential that the ceramic decorator join such a movement as this if he is to have an adequate understanding of the conditions involved.

7. *The pottery instructor, student and layman.* Enough has al-

ready been said in this statement to give a fairly comprehensive idea of the possibilities and opportunities in ceramic work open to those who are interested in following such a progressive movement as the one outlined. It affects everyone interested in ceramics. The greater the active interest the more comprehensive the actual results will be No one realizes the size of the program involved in the consideration of this crude outline more than those who are seriously and consistently planning and working it out to a definite successful result. But back of this realization is the knowledge of the great need for such an activity, a need which must be filled if we are to not merely compete in the world markets, but if we are successfully to hold our own in our own country.

FREDERICK H. RHEAD
Chairman Art Division

SEVEN CONVENTIONS IN ONE

Our Society has so increased its scope that the twenty-fourth annual meeting at St. Louis, Feb. 27th to March 3rd, inclusive, will actually be seven conventions in one. The seven divisions will meet separately except for two or three meetings of general interest and will make visits to the various plants separately. The list of papers to be presented, colloquiums to be held, and formal discussions on the program are so many and so varied that any one interested in any department in the Silicate Industries will find something especially arranged for him every hour of the five days.

Preliminary announcements have already been mailed to every member and the general program will reach each one before the Convention date.

One evening will be devoted to motion pictures and probably a theatre will be rented for the occasion. At this date (January 8th) five films are available: The Manufacture of Iron Sheets for Enameling; The Romance of Glass; The Manufacture of Face Brick; The Manufacture of Terra Cotta; and The Tale of the Tub, the latter showing the manufacture of porcelain and enameled bath tubs.

The subjects for forty-two papers are already in hand at this date and more than forty subjects for colloquiums and discussions are being considered.

To make it possible to have the maximum time for the technical program and plant visitations, the business session will be shortened, first by having all reports printed for distribution and not read, and second by having the inauguration of the officers at the banquet Tuesday night. There will be but one speaker at the banquet.

One evening, however, will be purely a social one and the old and well remembered SECTION Q gatherings will be emulated. This will be on Monday night and although called a Smoker, will be much more, ending with a dance. A surprise for each and all is in store.

The dates, February 27th to March 3rd inclusive. The place, St. Louis, Mo. Headquarters and meeting place for all sessions, the Hotel Statler. Make your reservations NOW.

The following members of the Papers and Program Committee each have charge of one of the Seven Conventions; ask them about the one in which you are particularly interested.

Terra Cotta Division. R. L. Clare, Federal Terra Cotta Co., Woodbridge, N. J.

Whitewares Division. C. C. Treischel, Gen. Elec. Co., Schenectady, N. Y.

Heavy Clay Products Division. C. Forest Teft, Watsontown, Pa.

Glass Division. Dr. E. Ward Tillotson, Mellon Inst., Pittsburgh, Pa.

Enamel Division. R. R. Danielson, Bureau of Standards, Washington, D. C.

Refractories Division. F. A. Harvey, U. S. Refractories Corp., Mt. Union, Pa.

Art Division. Miss Mabel C. Farren, 3600 Forbes St., Pittsburgh, Pa.

R. D. LANDRUM
Chairman

ORIGINAL PAPERS AND DISCUSSIONS

MOULDS FOR MAGNESITE, CHROME AND SILICA BRICK[1]

By Erling E. Ayars

ABSTRACT

Shrinkage.—Determination of allowance for shrinkage in mould manufacture is of prime importance. Design comes next.

Types of Moulds.—Slip moulds including the open slip and vent bottom types, steel slip liner moulds, and the wooden knock-down screw mould.

Materials Used.—Soft steel, cold rolled steel, galvanized iron and hard woods.

Moulding Tools.—The slicker, short scoop, smacker, putty knife, rammer and hammer.

Manufacture of Moulds.—Relation to the manufacture of all kinds of brick made from these special refractory materials. The treatment of each type of mould includes materials and method of manufacture, the materials and kinds of brick, the manufacture of which it is best suited, together with the manipulation best suited to turning out a uniformly good product. Correction of mould faults and suggestions for overcoming difficulties encountered in moulding brick find their place wherever the discussion of the various moulds and operations suggests any of the common troubles of the moulder.

Introduction

Moulds used in the manufacture of magnesite, chrome and silica refractories are divided roughly into three classes: slip moulds, slip-liner moulds and knock-down or screw moulds. One of the first considerations in mould manufacture is to determine just how the brick is to be set when fired. Experience will indicate the position of setting most likely to produce the least strain under fire and the mould is designed accordingly. In manufacturing moulds for magnesite and chrome brick it is necessary, as in the case of fire clay refractories, to allow for the shrinkage which occurs in burning. This amounts to approxi-

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[1] Received Nov. 14, 1921

mately one quarter inch to the foot, but varies with different classes of raw materials and should be determined for the raw material actually used. Magnesite and chrome brick tend to show undue shrinkage along the dimension perpendicular to the one on which they set while under fire. Chrome invariably behaves this way but there are classes of magnesite which do not exhibit this tendency to any appreciable extent. Experience is the only safe guide to follow. To offset this extra shrinkage due entirely to the weight of the brick itself, it is necessary to add, over and above the normal allowance of $^1/_4$ inch to the foot, approximately $^1/_8$ inch to 12 inch dimensions, $^3/_8$ to 15 inch dimensions and $^1/_4$ to 18 inch dimensions. No extra allowances are necessary on the other dimensions of the brick in this case. The importance of determining the setting influence before the mould is made is evident.

Moulds for silica brick are made with three different allowances for expansion in burning. Generally speaking, dimensions under 6 inches are allowed $^1/_8$ of an inch to the foot, over 6 inches and under 12 inches, $^1/_4$ inch to the foot, and over 12 inches, $^3/_8$ of an inch to the foot. The usual practice allows $^3/_8$ of an inch to the foot for length, $^1/_4$ inch for width and $^1/_8$ inch for depth. In dealing with large silica brick such as coke oven shapes, it is necessary to make even greater allowances for expansion than those mentioned, sometimes as high as $^1/_2$ inch to the foot. The variation in expansion of silica brick seems to be directly related to the mass represented and no definite rule can be given for any one material. The weight of individual pieces or of an entire bench as set in the kiln does not seem to affect the amount of expansion in a brick, provided of course the same heat treatment is extended to all.

Shrinkage and expansion rules may be obtained from any manufacturer of rules and are best made of spring steel. Wear on such rules is negligible and they do not bend like brass from which rules are occasionally made. When using three different rules as in silica mould manufacture, it is well to have different standardized gauges and widths for each rule, to avoid confusion and loss of time in handling.

In mould manufacture there are several things to consider in choosing the type of mould to be used. Among the first is the ultimate cost of the mould. This must include first cost of material and labor in constructing the mould and repairs, which may be excessive in certain types of moulds.

Quantity and quality production after the mould goes into service is a big item and must be considered. With some moulds quantity production is impossible if quality is to be maintained. The same brick may be turned out in good quantity with equal quality from a mould of different design and construction.

The number of brick which are to be made must be considered also. An expensive mould should not be used for the manufacture of a few pieces if it can be avoided. In general the cheapest mould which will give the largest output and best quality should be made in all cases. Very often the most expensive mould from the standpoint of first cost is the cheapest in the long run. The mould maker must have a fund of experience to draw from and make his decisions in the light of past practice. Good moulds are the first step to a uniformly good product.

Slip Moulds

Slip moulds, employed almost entirely in silica brick manufacture, are of two kinds. First, the open-slip mould which is made in a gang of from four to six moulds and used with a slop mud only. The maximum size of brick to be made in this type of mould is limited to those which may be filled by the roll of one "Walk." Standard 9 inch sizes and similar brick are as large as one may expect to get good results with. Some manufacturers make 12 and $13^1/_2$ inch standard sizes and brick of similar dimensions in gang moulds of this type, but better quality can be obtained in this range of sizes by making a hammered brick, in which case the second kind or vent-bottom slip mould is used, and stiff mud employed.

To construct a gang mould of the open-slip type, $^3/_8$ inch soft steel is generally used (Fig. 1). The length of the gang is the combined width of the number of brick to be made plus allowance for thickness of the webs, with sufficient stock at both ends for hand holds. The width is determined by the length of the brick itself, and the depth in the same manner. Brick not exceeding

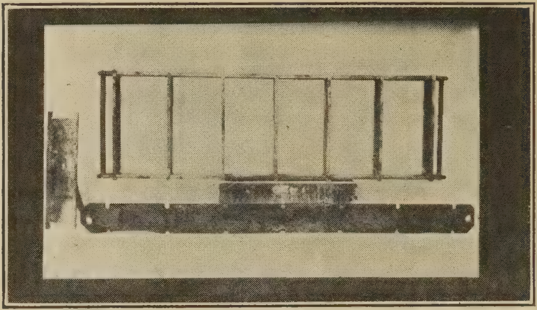

FIG. 1.—Showing the construction of the open-slip mould, the slotted side piece with holes drilled for hand holds, a web, and a complete mould.

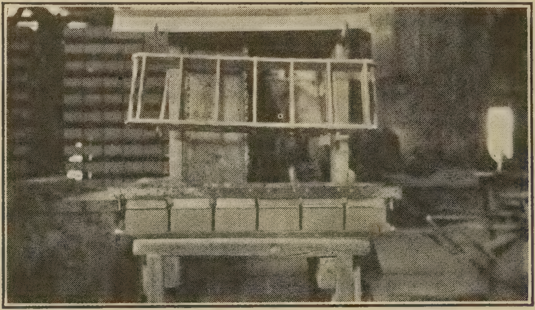

FIG. 2.—Showing a push board resting on a pallet of brick. The mould which has been dumped is seen in the rack above. Notice the slots in the push board into which the webs of the mould fit as it is lifted clear of the brick.

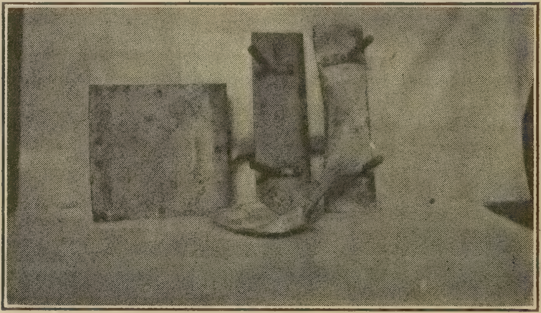

FIG. 3.—A "smacker," the "short scoop" and two "slickers," one of which has long since ceased to be useful.

$2^1/_2$ inches in thickness are made in this type of mould. Steel $2^3/_4$ inches wide is used in making moulds for $2^1/_2$ inch brick to give a little stock to dress on, so that the top and bottom of the mould may be exactly parallel. The same plan is followed in making moulds of any depth.

The side pieces are slotted top and bottom at the proper interval, and the webs, with projections to correspond, are fitted into the slots and riveted in place. Great care is necessary in laying off the position for the webs and good workmanship is essential, that the mould may be square and all webs perpendicular to the plane of the top and bottom when the whole is assembled. The side pieces project at each end about $2^1/_2$ inches beyond the outside webs in order to provide hand holds. These are made of $^1/_2$ to $^3/_4$ inch steel rods riveted through the side pieces and add rigidity to the mould.

The bottom of this mould consists of a flat steel plate $^1/_2$ inch thick, not fastened to the mould, but hinged to a heavier plate which is securely fastened to the moulding table. The bottom plate has a margin outside the mould of one inch on each side and 2 or 3 inches on each end. Four pins are placed in the top of this plate so as to fit into the exterior interior corners of the mould and secure it while the moulds are being filled and struck off. As soon as the brick are struck off, a pallet is inverted on top the mould. A rack, hinged to the moulding table, facilitates turning the mould and its contents over onto the pallet. The bottom is returned to the flat position, another mould laid on and filled, etc. A push board applied to the bottom of the inverted mould exerts a pressure against the brick as the mould is pulled off and prevents the deformation which occurs if the mould is lifted directly off the brick (Fig. 2).

Moulding Tools

Moulder's tools and their use will now be described. The slicker or striker is made of hard flat steel $^3/_8$ by 5 inches. The length varies according to the work in hand but is usually from 15 to 18 inches. The tool is provided with two handles at convenient intervals having a suitable angle with the working face.

The working or cutting edge is beveled back about $^1/_2$ inch on the bottom side. The slicker is used with all types of moulds and all types of products.

In manufacturing silica brick in vent-bottom, slip liner and screw moulds, the material is scooped into the moulds, rammed down into the corners with the short scoop handle, filled heaping full and pounded down hard with a "smacker," struck off with a slicker and dumped onto the pallet. The "smacker" is made of any wood which does not split easily and should not be less than $1^1/_4$ inch thick. The size varies with the mould it is to be used with. Ordinarily "smackers" are not as long as the mould but should be equally wide. One face is covered with $^1/_8$ inch flat iron and the handle is fastened to the other face. To guard against splitting, two slats are fitted to the back at either side of the handle, the grain crossing the grain of the large piece. All parts are fastened together with stove bolts (Fig. 3).

In moulding magnesite and chrome, the mould is partially filled with material which is rammed down hard into the corners and edges with a small steel rammer. This is then loosened on the top surface with a scratcher or fork. More material is piled in and heaped above the mould top. A large wooden hammer is used to pound it solidly into the mould, after which it is struck off and the brick dumped onto the pallet (Fig. 4).

Vent-Bottom Slip Moulds

Vent-bottom slip moulds are used exclusively in silica brick manufacture. The mould is made in practically the same manner as the open-slip mould previously described except that it is furnished with a solid bottom. Various designs may be used based on the desired arrangement of the brick as they lie on the pallet, and on the size of the brick to be made. The size of pallet available is generally the determining factor. For instance, a two-brick mould only can be used with a 12 x 9 x 3 brick and standard 9 inch pallets, while a 14 inch pallet will permit the use of a three-brick mould. The several styles of vent-bottom moulds shown illustrate the possibilities in construction (Figs. 5*a*, 6*a*).

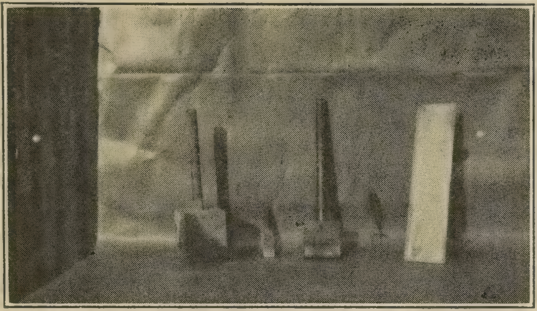

FIG. 4.—The "rammer," "fork, hammer, and slicker" used in the moulding of magnesite and chrome brick. The putty knife is used for cleaning the mould.

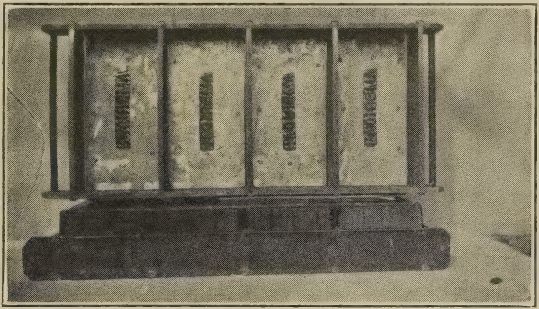

FIG. 5.—(*a*) Type of vent bottom mould used with 14″ pallets, showing top and side view.
(*b*) Notice the thickness of the bottoms, the galvanized iron lining of the bottom and the vents. The webs are seen to extend below the top surface of the bottoms.

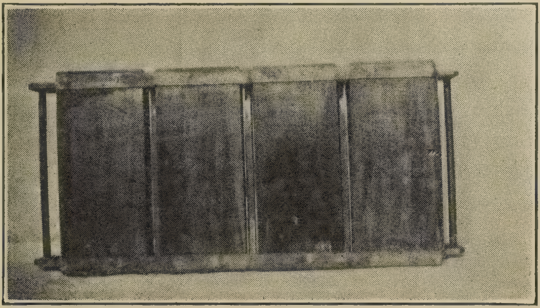

FIG 6.—(*a*) A back view of the mould shown in Fig. 5.
(*b*) Notice the vents, the strap iron binding and the beveled wooden bottom adjacent to the vents.

On account of the working principle of the mould a 4 inch depth appears to be the practical upper limit and this is attainable only in case the width is about the same or does not exceed six inches. The standard 12 and 13$^1/_2$ inch sizes with depths of 2, 2$^1/_2$ and 3 inches are all easily made in these moulds, as are also 9 inch sizes.

Bottoms for these moulds are made of 1$^1/_2$ inch maple lined with 16 gauge galvanized iron. A small vent from $^1/_{16}$ to $^1/_8$ inch wide is left between the side of the mould and the bottom for the admission of air when the mould is turned for dumping thus allowing the brick to slip easily from the mould. The width of the vent depends both on the depth of the mould and the area of the mould bottom. Brick with a large area require a larger vent than those of smaller area since, on account of the soft condition of the brick the sides and ends have a tendency to lag behind the center in dumping, which results in a poor product. The vents are always made on the two longest sides of the brick. Needless, to say, they must be kept open by regular cleanings. A putty knife is generally used for this purpose (Fig 5*b*).

It is important that the sides or webs of the mould forming one side of the vent shall extend below the upper surface of the bottom about $^1/_4$ inch. This method of construction has two advantages. If the bottom of the side piece is on a level with the top plane of the mould bottom, more or less of the brick mixture will be forced out through the vent in pounding. This forms a fin which breaks off when the brick is dumped, leaving a rough rounded edge. The purpose of the vent is defeated as soon as it becomes filled with brick mixture, as in this case. Grains of rock are forced into the vent and wedging there are difficult to extract. Such a vent will wear rapidly and soon become too large to give even passably good results and the brick turned out will have widely rounded edges. By extending the side pieces below the top plane of the bottom, these faults are prevented and the result is a brick with sharp, well-formed edges of proper density.

To further improve the working qualities of the vent, it is desirable to bevel the wooden bottom back from the vent. This seems to admit more air and increases the speed and force of its entry.

After the bottom boards are secured in their proper places by means of stove bolts which are tapped into the ends of each mould box, the bottom is ironed with $^1/_8$ by 1 inch strap iron. These straps, secured with wood screws, cross the ends of the bottom boards and afford both resistance to wear and added strength to the mould (Fig. 6*b*).

Steel Slip Liner Moulds

Slip-liner moulds are used either in magnesite, chrome or silica manufacture and are made wholly or in part of steel. The mould box is usually made of $^3/_8$ inch soft steel which can be obtained in almost any desired width. The best method of making these boxes is as follows: The end pieces are cut to the proper inside dimension, measuring through the center. Projections at top and bottom are left which fit into slots in the side pieces, much on the order of a mortise and tenon joint. These projections on the end pieces extend beyond the thickness of the side piece far enough to allow for upsetting. Needless to say the slots and projections must be fitted accurately and an easy-driving fit is desirable. The slotting is accurately done on a shaper or planer. The side pieces are longer at each end, by $1^1/_2$ to 2 inches, than the mould box proper. Pieces of $^1/_2$ to $^3/_4$ inch round steel for hand holes are fitted into holes in both sides and riveted in place. These should be closely fitted and riveted in order to add to the strength of the mould box (Figs. 7, 8).

A good bottom is very important if the mould is to give satisfaction. The full steel bottom is most desirable and is made of $^3/_8$ inch soft steel. It should be of one piece, no matter how wide. On account of the vibration incident to moulding, a 2 piece bottom will not give good results. The sides and ends of the mould box are slotted with a $^3/_8$ groove allowing a margin along the lower edge, of from $^1/_4$ to $^1/_2$ inch, into which the bottom must be fitted before it is riveted together. It should be fitted with such accuracy that the box is absolutely true and tight. Good workmanship is most essential. With long moulds it is necessary to take account of the spring of the sides and bottom which is an inevitable result of the pounding during the manufacture of the brick. With the steel-bottom mould a wider margin is left when the grooves

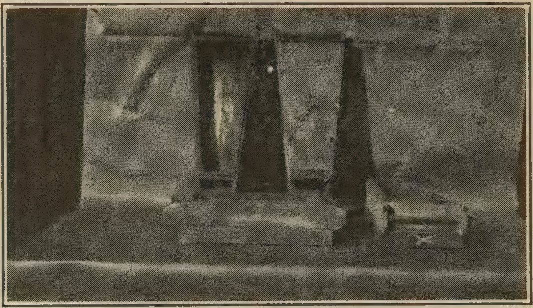

FIG. 7.—Simple types of the slip-liner mould having plain sides and bottoms only.

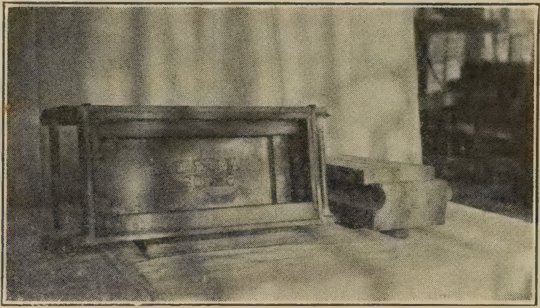

FIG. 8.—A mould illustrating the use of the tongue and groove as applied to making of liners. Notice also the irregularity in the nature of a step at one end of the bottom.

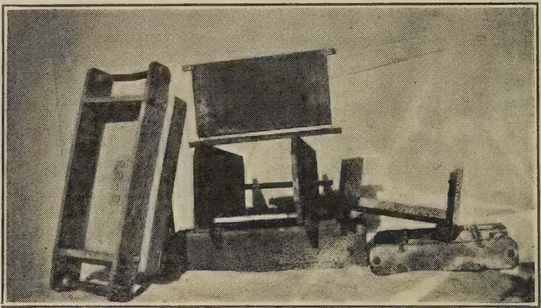

FIG. 9.—In the center of this figure we have an illustration of the best type of mould bottom. Note the slot near the bottom of the side pieces and also in the end piece resting on top of these side pieces. A piece of flat steel was placed in the slots of the side pieces to hold them in position and simulate a bottom. At the right the second method of bottom described is illustrated. Note the square shoulders riveted to the side pieces, the bottom being riveted to the shoulders. At the left is shown a wooden bottom lined with galvanized iron.

are cut in the sides and ends, and one or two $^3/_8$ steel rods are fitted into holes in the sides under the bottom and riveted in place after the bottom is put in. This keeps the sides from spreading appreciably and reduces the amount of spring in the bottom (Fig. 9).

A method used extensively in manufacturing bottoms for this type of mould requires a shoulder of $^1/_2$ inch square steel riveted to the sides and ends of the mould box on which the bottom rests. The bottom in turn is riveted to the shoulder. This type of mould bottom requires more material and labor and has perhaps less strength than the one previously described.

Another method of making the bottom which is very satisfactory for narrow moulds only, is to put on a wooden bottom lined with galvanized iron. Only well-seasoned hard wood should be used. Maple from $1^1/_2$ to 2 inches thick is the most satisfactory. After the mould box is put together the maple is cut to leave a $^1/_2$ inch margin all around the outside of the box. The lining of 16 gauge galvanized iron is fastened to the wood with small flat-head screws countersunk slightly below the surface of the iron. These screw heads are covered with a hard solder to make a smooth surface. The bottom is then fastened to the mould box with suitable stove bolts or machine screws tapped into the steel sides and ends. The heads should be countersunk into the wood and drawn up tightly against washers. When the bottom has been applied three straps of $^3/_8$ by $1^1/_2$ inch soft steel are fitted across the ends and middle of the bottom by gouging grooves $^1/_4$ by $1^1/_2$ inch into which the straps are fastened. Flat headed wood screws are used and the heads countersunk below the surface of the steel. These straps reduce the possibility of warping of the wooden bottom and resist wear when the mould is put into service. If no straps are used, the sides and ends of the wood wear off rapidly and the mould begins to rock back and forward as the brick is made. Imperfect brick are sometimes traceable to this fault. The full flat bearing which the straps give is essential for satisfactory mould service.

The liners are the next consideration in building the mould, although the proper form and dimensions of these should be figured out in advance so that the dimensions and form of the mould box may be determined. It is always advisable to make a sketch of the entire mould with dimensions, which have been carefully checked against the dimensions of the finished product, using a shrinkage rule in the case of magnesite and chrome brick and expansion rules in the case of silica brick. Liners for plain rectangular brick are made from $^3/_8$ soft steel. Liners for brick having tongues and grooves must be proportionately thicker to take care of this irregularity in shape, or tongues and irregular shaped blocks can be riveted to the liners. It is advisable to use flat steel which is a little wider than the mould depth so that a few cuts may be taken on each edge to insure even bearings of the liner against the bottom of the box and regular depth throughout the length and breadth of the mould (Fig. 10).

There are several methods of joining the liners at the corners. The simplest method is probably the best, and consists merely of butting the end of each liner against the face of the one preceding it. This type of joint must be made true. It is easily cleaned and refitted. The miter joint, which is used to some extent, is harder to keep clean and refit and unless the dimensions of the liners are absolutely true to the dimensions of the mould box, the joint may spread, ever so slightly, leaving a featheredge at the corners of the brick. Cracks are a common result of this featheredge. Occasionally one may use a modified interlocking form of the first joint. This is hardest of all to keep clean and refit and is not considered a good joint on that account. Joints of any type, other than the first one mentioned, add more or less to the cost of the mould without improving its working qualities measurably and very often reduce the daily output of brick. It is sometimes necessary, however, to use one of these less desirable joints in moulds having liners of different thicknesses and where tongues and grooves are required.

To guard against the moulder's incorrectly placing liners in the mould box it is well to put a short pin in one side liner and one end liner, notching the mould box to correspond. These liners will not fit except in the proper place and will avoid troubles arising from inverted liners.

To insure easy removal of the moulded brick from the mould box a splay of approximately $^1/_8$ inch in 6 inches from the bottom

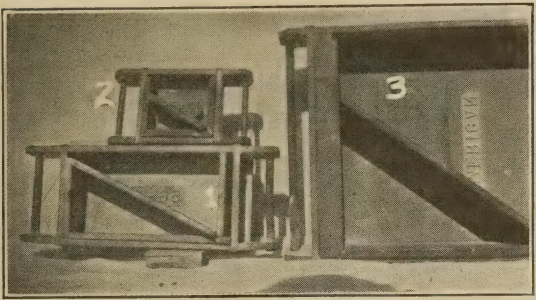

Fig. 10.—Mould 1 illustrates the method of butting the end of each liner against the face of the one preceding it. In mould 2 we see the miter joint, and in mould 3 the interlocking idea used in connection with the "butt end" liner.

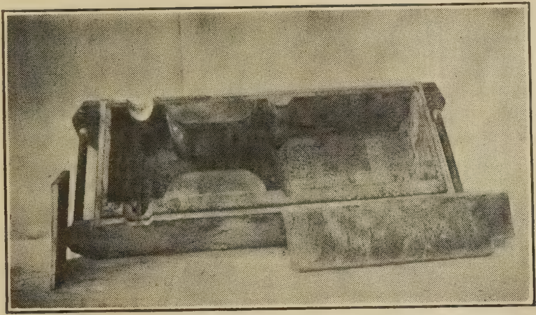

Fig. 11.—Illustrating the "splay" used in fitting liners to the mould box. The liner standing in front of the mould shows the splay at the end. The edge of the liners standing against the end of the mould shows the splay of the face, the top in this case being about an eighth of an inch thicker than the bottom.

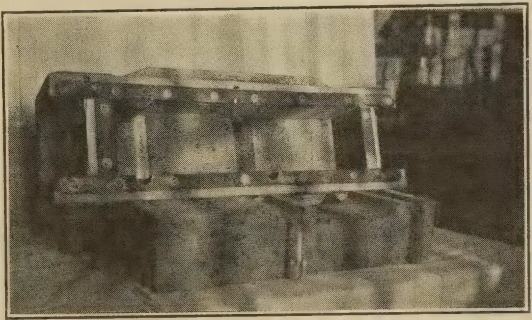

Fig. 12.—A wooden-screw mould and its product. Note the tongues and grooves and other irregularities of the brick. The brick is turned end for end but otherwise lies just as it would when dumped from the mould.

to the top of the box on both sides and both ends is allowed when the box is made, and the backs of the liners are machined to fit this, the working face of the liners being perpendicular to the bottom of the mould or having any angle with the bottom that is required in the brick (Fig. 11).

It is often possible and profitable to construct moulds of this type to make two bricks at a time, where the shape of the brick readily lends itself to such treatment. Two complete moulds are made with bottom, sides and one web common to both. Good results cannot be obtained if the separating web serves also as a liner, for it is held firmly between the brick after they are dumped on the pallet and there is danger of damaging the brick when it is removed. Two moulds together are filled almost as rapidly as one, rammed, hammered and struck off just as rapidly, so that more brick can be turned out by the same moulder in a day. Wherever the size and shape of the brick and pallets available permit such treatment it is recommended. Drying capacity may be doubled in this manner where it has been the practice to use a pallet to each shape.

Generally speaking there is no limit to the length of life of a well made all steel mould box, but wear on the top edge of the mould liners incident to slicking off each brick is considerable. The "slick" side of a brick produced in a worn mould exhibits a depression midway between the ends of the brick instead of the proper true flat surface. With some materials containing a limited amount of moisture such a brick will crack when turned onto the pallet, as the center will sag to conform to the flat surface of the pallet. Other materials containing more moisture will permit the sagging without forming a noticeable crack, but under fire the crack develops and the brick becomes a cull. Liners should not be allowed to remain in service until they produce such brick, but they do not need to go to the scrap pile.

In the hands of a competent mould maker the life of a liner may be extended to several times the length of the first wear. The liner is heated in a forge, laid on a flat steel plate with the working face down and stretched by means of a "fuller" which is applied parallel to and about $^1/_2$ inch from the worn edge. Two or three heatings may be required to obtain the proper amount of stretch.

The liner is then placed in a shaper and 2 or 3 light cuts made to true up the edge, and reduce the depth to the proper dimension. Generally there is a slight stretch lengthwise which may be ground down on an emery wheel. The liners are replaced in the mould box and will give as good wear as when newly made. The number of times a liner may be stretched in this manner depends on its width and the skill of the mould maker. Blocks and other irregularities riveted to the working surface of the liner should be removed when the stretching is done. Invariably these attachments will fit back into place with little or no trouble.

Wooden Knock-Down or Screw Moulds

Knock-down or screw moulds are made of wood lined with sheet iron, on the ends, sides, and edges to resist the wear, and joined at the corners by tongue and groove methods. The bottom is furnished with a shoulder having the same shape and dimensions as the inside of the mould, and is secured by clamping the sides down hard against the shoulder. Dowel pins are often used to insure correct fitting of the sides, ends and bottom together and contribute to the general rigidity of the mould (Fig 12).

Well-seasoned maple is probably the best wood to use in screw mould construction. It is less liable to split and warp, will take and hold screws and makes a good wearing job. Poplar may be used but is not so satisfactory. Soft woods and woods with a decided grain should never be used. The thickness of the wood selected should not be less than $1^1/_2$ inches and longer mould life is obtained when $1^3/_4$ and 2 inch stuff is employed.

Screw moulds (Fig. 13) have been used almost entirely in making large odd-shaped brick, in cases where it is difficult to design a satisfactory steel slip liner mould or when only a few pieces of a certain brick are required. In such cases the life of the mould will be in excess of the amount of work required of it. When put to considerable use, first cost is very often a small item compared to the repairs necessary to keep the mould in service. One of the first difficulties experienced with wooden moulds arises from swelling and warping which make it difficult, and eventually impossible, for the moulder to reassemble the mould properly.

Several poor brick are made during this time and as soon as the mould is checked as faulty it must go to the shop for repairs. While it remains out of service no brick are made. The side of a deep mould will split under the hammering of the moulder thus necessitating further repairs. When once the side is split, the mould becomes a cripple and will need constant attention, and brick made in it will not always stand rigid inspection. Even with a perfect screw mould, there is also the possibility that the moulder will fail to properly tighten it when putting it together. Poor brick are the result. The class of men employed as moulders should be furnished with tools as nearly "fool-proof" as possible. A wooden mould is far from being such a tool. It does not readily fall back into place after having been once taken apart for dumping a brick. As a result, the possibility of poor brick is very pronounced and only men who are capable of taking an intelligent interest in their work can handle a wooden mould profitably for themselves or their employers.

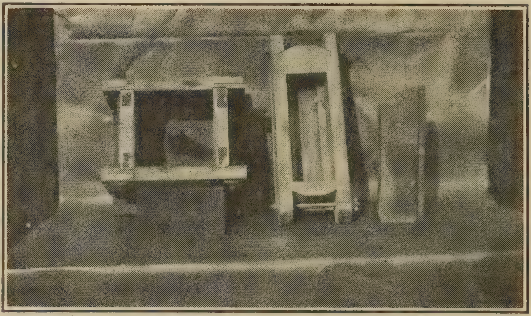

Fig. 13.—Two small screw moulds, one for a tap-hole and the other for a tuyere brick which stands beside it.

On account of the limited uses to which chrome brick are put, press-made standard 9 inch sizes fill nearly all requirements and as a consequence almost no hand-moulded chrome are made. However, some tap holes and nozzles are used and either slip liner or wooden screw moulds are used in their manufacture.

Magnesite standard 9 inch sizes and a great variety of special shapes are now made by the press method and the matter of hand moulding in this branch of the industry will receive less and less attention as time goes on, due to the diminishing number of special brick which require hand moulding.

Until recently silica brick have always been exclusively hand moulded. At present time a machine for the mechanical moulding of standard 9 inch sizes is being developed which may in time be adapted to manufacturing the larger standard sizes. It seems probable that mechanical moulding of these standard sizes should within a short time altogether replace hand moulding. This will be a long step in the right direction for while the purchase and use of refractory products will always be subject to caprice and prejudice born of false theories and poorly taken or incomplete information, their manufacture should not be affected by the human element to such an extent. Mechanical moulding will eliminate a great deal of the personal equation.

A large proportion of the breakage encountered in the manufacture of hand moulded refractory products may be traced to the variation in density in different parts of the brick when it comes from the mould which results in uneven expansion or shrinkage while under fire thus producing cracked and deformed brick. Beyond doubt this is due to the uncertain treatment which the brick making mixture receives at the hands of the moulder. This condition is almost entirely eliminated in press made brick where the personal equation is not operative.

Special shapes of silica will probably always be hand moulded on account of the diversity of sizes, shapes and uses. Mechanical moulding of this class of product would demand similar machinery to that used in manufacturing electrical porcelain and would require a radical departure from the mud mixtures now used. The investment necessary for moulds in such a case would be out of the question as changing practices among the users of this type of product will not permit a standardized brick. This is particularly true of coke oven brick. It is, however, within the range of possibility that large shapes of all kinds will soon be made on the same principle that is now being developed for the manufacture of the standard sizes, although the chances of automatic dumping devices in this connection seem to be very remote.

It has been said that in another twenty years coke ovens will be constructed out of standard 9 inch or similar sizes and that special shapes now used will be discarded entirely. In that case hand moulding of silica brick may be done away with altogether. This will mean radical departure from present day practices but there is reason to believe that such changes will come and they are bound to be profitable both for the manufacturer and the consumer.

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GLASS CONTAINERS[1]

A. W. Bitting

ABSTRACT

For centuries glass bottles have been recognized as superior containers. At present over 4000 different sizes and shapes are being made and the industry is in a state of rapid extension. Glass containers possess the advantage of being sanitary and permitting the contents to be seen. Recently the laboratory of the Glass Container Association has tested 180 lots of beverage bottles. Some of the better types, or those approaching the champagne style, were found to withstand an end crushing pressure of from 8000 to 12000 pounds, a transverse pressure of from 800 to 1800 pounds, a hydrostatic pressure of from 400 to 1600 pounds, and an impact of a fifty-pound hammer falling from 2 to 6 feet. Similar tests are in progress on other types of containers and on the closures employed. Troubles due to alkalinity are of rare occurrence.

Historical

Nearly thirty-five hundred years ago a Theban ruler, Amenophis, erected the great granite monument, the Colossus of Thebes, and inscribed his name thereon. The granite typified endurance and resistance to all time. But the centuries have wrought destruction and the elements have worn away the surface so that the name is gone except as record of it remains in history. Within this monument was a delicate scent bottle made of yellow glass and upon it is inscribed in blue characters the name of this same king. This light fragile bottle, protected by the heavy granite walls of the tomb, connects the present glass industry with that period. It is the earliest glass bottle known to be marked in such a manner that it may be identified with some person, place, or date. Glass ornaments for personal adornment are known to have existed for many centuries prior to that time; some of the drawings in earlier tombs show bottles being used for wine, but this marks the beginning of known specimens.

It is not at all strange that the early pieces were for scent bottles, perfumes, ointments, and other toilet preparations as they were

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necessarily small and costly. They would appeal to the rulers and to the wealthy few as next to jewels and insignia. They evidently served well as precedent for at no time since have they been supplanted for the purpose; the highest skill on the part of workmen, blowers, cutters, decorators, and jewelers has been and is still expended in fashioning them. Their appeal is not only to those of means, but highly artistic forms are made to meet the wishes of all who feel the need of cosmetics to accentuate their personal charms.

The wine bottle receives a particularly early mention and its advantages as a container are made a matter of record. It seems to have been among the first of the bottles of fairly large size, and the first to have been made in quantity after the art of blowing was introduced. The Phenicians added the seal or date to this bottle. The advantage of long aging of wine seems to have been fully appreciated and in the period of the Roman empire Horace observes at a feast that "They immediately bring in glass bottles carefully sealed; on the neck of each is a label, marked thus: 'Opinion Falerian one hundred years old.'" Pliny states that some of this vintage was held for two hundred years. The bottle continues to maintain its place as preëminently the container of choice where wine is made.

Galen, the most celebrated of the Greek physicians gave an impetus to the use of the bottle for holding medicines or pharmaceuticals, "because from it cometh no smell or bad odors." In the excavation of the ruins of Pompeii a surprisingly large number of bottles were found showing how the "ancient housekeepers, kept their wine, oil, vinegar, honey, preserved apples, dried figs, prunes, beans, and barley." Some bottles of similar form are still in common use. The progress since that time has been in the production of a better and more brilliant quality of "metal" and the uniformity in size and finish which comes from the application of modern mechanical methods.

The glass industry was the first manufacturing enterprise to be established in this country. A furnace was built near Jamestown, Va., in 1608, where a few bottles were made, some of which were sent to England the following year. Ever since then glass factories have followed the march of the settler and met his requirements. The one outstanding feature of the development of the industry in America has been the application of mechanical processes to reduce hand labor and to secure greater brilliancy of "metal" and uniformity and accuracy in containers. The glass industry has always been considered one which is unusually hazardous, the life expectancy of its workers being rather short. It has been a seasonal occupation with much time lost in idleness. The substitution of coal for power, and the adoption of inanimate machines which know neither hot nor cold weather, nor hours nor days, to turn out containers from one-fourth of an ounce to twelve gallons at a speed and low cost which permits their use in hundreds of ways, was never contemplated by the most imaginative even a hundred years ago. The most rapid transition in the entire history of the industry is being enacted at this time. It will only be a little while until the machine will supercede all hand work as completely as the power loom has for woolen cloth. There will always be a place for the human glass blower who has the artistic taste and skill to execute the exceptional article for limited use and quantity, but not in competition with those forms or patterns which are turned out by the thousands.

Types of Glass Containers

The present glass container is a good deal like Topsy; it "just growed." It is supposed to represent the whims and desires of hundreds of users, but more likely represents the persuasive efforts of many salesmen from the glass factories. These salesmen have taught their customers that there is vast wealth to be obtained by distinctive designs. Possibly there is, for it is said that we have more than four thousand shapes and sizes and special designs, not counting names or trade marks. The result is containers of all kinds for all purposes, many good ones, some indifferent, and some poor. From this heterogeneous mass there will gradually evolve standard types to care for the business in different lines. There will come a recognition that the glass container has two quite distinct functions, one to carry and protect its contents while at the same time making them visible to the user; the other, to serve as an ornamental package. The ornamental qualities in glass are so naturally inherent that attempts to combine the latter functions with the former have resulted in hundreds of monstrosities which are weak as carriers and devoid of artistic merit. There is a place for the container *per se* and another for art glass. Fortunately too, strong carrying bottles can be made with attractive lines, good proportions, and clean "metal," befitting both the contents and the package. Manufacturers and packers will learn in time that tall bottles and jars with narrow bases can not be handled with the same ease by machinery as the more sturdy types. They will learn too, that they can not handle a dozen to twenty sizes and shapes with the same economy as two or three and that the differences in cost are not due to the glass used but to the stock carried, greater number of machines needed, increased labor in handling, multiplicity of labels, cartons, and shipping cases, and the storage space required. Through the costly school of experience they will eventually learn that certain shapes lend themselves to pasteurization and processing better than others, and that the laws of physics relating to expansion and contraction can not be set aside just to have a panel bottle. Boards of Health through the enforcement of ordinances requiring the cleaning and sterilization of re-usable bottles, as for soft drinks, will gradually drive home recognition of the fact that some styles are much more difficult to clean than others. The present studies upon shipping will cause some manufacturers to take notice of the fact that those forms which present a large surface to resist impact will carry much better than those whose form presents a small area to receive the blow. In other words, the manufacturer of glass and the user of glass are arriving at the point where they must work together on their problems, if quantity and economical production are the ends to be sought by both. If this sounds like an array of the faults or weaknesses of the glass container, nothing could be farther from the intent. It is a pointing out of a few of the factors at work which will bring about greater changes and more rapid extension of the use of glass in one or two decades than have ever taken place in a century.

American made glass containers may be classified as follows:

Beverage bottles: Pressure ware, for carbonated sodas, ginger ale, etc.; non-pressure ware, for mineral waters, grape and other fruit juices, etc.; milk; and liquor containers.

Proprietary and prescription bottles: Round, oval, square and panel bottles for patent and proprietary medicines, prescriptions, flavoring extracts, etc.; perfume and toilet bottles.

Food containers: Wide mouth, for preserves, jams, jellies, marmalades, etc.; narrow mouth, for sauces, ketchups, salad dressings, syrups, vinegars, etc.

General purpose containers: Wide mouth, for dry drugs, chemicals, and heavy materials; narrow mouth, for drugs and chemicals, oils, varnishes, polishes.

Large containers: One to twelve gallon bottles and carboys, for water bottles and chemicals.

Special containers: For battery jars, display jars, etc.

Extension of the Use of Glass Containers

At the present time there is a rapid extension of the use of the bottle for soft drinks and the materials used in their manufacture. There are two reasons, one being the eighteenth amendment to the constitution, which is probably not the greater, the other that the ordinary soda fountain is not sanitary. The local water supply in hundreds of towns and smaller cities is not protected from pollution, and discriminating people prefer to obtain their refreshments in a container which has been handled and filled in a place where sterilization is a part, and a fundamental part of the business. Uniformity in quality through exact compounding, and safety of the sterilized product do appeal, and even the unthinking gradually acquire the habit of "safety first." The soft drink industry has had a sudden and unexpected growth which has been to its disadvantage, but as it becomes older and acquires a normal development, it promises to expand to larger proportions than the bar trade which it has supplanted. Its patrons are the whole family instead of only the head, and if properly developed with the use of wholesome materials, it must necessarily follow that there will be continued growth of the industry with a large extension of the use of glass.

The milk bottle was born of progress and was christened only a few years ago. In two decades it has almost supplanted the tin can and dipper in every city and village in the country. The greatest stride in making milk safe and wholesome has been based upon this cleanable, sterilizable container, and the limit of expansion has not been reached.

Liquor containers or containers for spirituous and fermented liquors have suffered a marked decline in number and no comment is necessary.

The other field of increasing interest is that of the food container. When one enters the grocery store in the largest city or smallest village, the most prominent feature on the shelves is row upon row of canned foods. The impression is gained that no others are packed, but such is not the case. We have the means of knowing how many preserve jars are made and the amount of ware produced for jams, canned fruits, etc. We also have a fair notion of the re-use of jars in the home. The total quantity packed in glass is far in excess of that previously estimated even by food experts. The art of food preparation has not all passed from the kitchen to the factory and if we may judge from the number of capping devices sold, the art, or at least the labor of home brew, is returning to the same place. The amount of new foods in glass is increasing by leaps and bounds. Peanut butter was an oddity ten years ago, but is now almost a staple. Mayonnaise dressing and salad dressings of a similar type which were made only to fill in a complete line of groceries, and even sold in split cases, now require millions of bottles and will soon rival ketchup in the quantity required. Vinegar and pickles are being taken out of the class of barrel or bulk delivery in favor of the individual, sanitary package. The former alone will require several million more bottles this year than ever before. Syrup manufacturers have learned the lesson from honey distributors, that people do, in a sense, eat with their eyes and like to see what they buy. Experiments conducted in the laboratories of the Glass Container Association have demonstrated that there is a decided gain in holding nut meats in vacuum jars, that in these containers there is less change due to drying, that they may thus be kept during the summer without refrigeration, and that the rancidity of the oils and the development of a bitter taste may be avoided. This suggests other experiments and possibly new uses for glass.

Experimental

While the foregoing indicates very briefly the lines in which expansion is developing most rapidly, there is another phase of industrial activity set in motion to keep pace with the expanding uses, and that is the study of the container itself. The bottle or jar is not complete without a proper closure, and the history of the numerous efforts made in this direction is told in the long list of patents granted by the Patent Office. A great deal of inventive genius has been expended along this line, but most of it has come to naught. The best bottle or jar, used with the best designed closure, will not work unless the two fit, and as a rule the makers of each have not known the limitations of the other. In order to avoid such difficulties in the future, the glass manufacturers and the closure manufacturers are working together, fixing the standard sizes of openings, the height, thickness, and pitch of the thread for all screw caps, the shape of the lip for crowns, and the finish for various other closures. This means standard molds for the one and dies for the other, and most important of all, an insured tight seal to the user. This is but one step which eliminates hundreds of off-size designs and which gives a flexibility in purchasing not heretofore enjoyed. It will take time to complete this work but it is well under way.

The bottle itself is being subjected to study along new lines. During this summer, the association laboratory tested one hundred and eighty lots of beverage bottles as a preliminary step in determining their strength and suitability to meet certain requirements. There were no precedents to serve as guides, and therefore no handicaps in that direction. Direct pressure was applied both vertically and transversely to the exterior of the bottle. The pressure was applied by means of a screw and scales for some of the lighter bottles, but the majority required a regular testing machine. A piece of sheet copper was placed between the bottle and the metal of the testing machine. Hard maple was first tried but the mouth of the bottle was frequently forced into the wood to the distance of one fourth inch or more. Crown seals placed over the mouth assisted but were not sufficient as they were sometimes imbedded in the wood. The transverse pressure was obtained by placing the bottle between two pieces of hard wood, two and one-half inches wide and at least one inch above the bottom. These tests show that beverage bottles have a high resistance to direct pressure. Many bottles withstood vertical pressure between 8000 and 12000 pounds and transverse pressure between 800 and 1800 pounds. Whole groups averaged better than 5000 pounds vertical pressure and 1000 pounds transverse pressure. As the glass in a transverse section of the smallest part of the neck of a bottle is often much less than one-half a square inch, these figures give a compression strength to bottle glass somewhat higher than has usually been thought to be possible. A hydrostatic pressure was obtaind by filling the bottle with water and then using a pump and recording the breaking point. Some of the heavier bottles recorded 1600 pounds before breaking and several groups showed an average in excess of 400 pounds per square inch. This likewise is greatly in excess of the pressure of any of the highly carbonated beverages. An impact test was applied by fastening a hardwood butcher's block to a steel frame and resting the bottom of the bottle against the block. A hammer was provided with a handle five feet in length and suspended as a pendulum. A hardwood block was interposed between the bottle and the hammer. These bottles withstood drops of a fifty-pound hammer from a little less than two feet to more than six feet, or, corresponding to from 85 to 300 foot pounds. This impact test probably has more value than the direct pressure tests, as it is from blows of one character or another that most failures occur in glass in ordinary usage. A further test was made of the power to withstand sudden changes in temperature. The bottles were immersed in cold water and then transferred to a bath one hundred degrees higher. This is as wide a range as would be found in commercial practice in washing or sterilizing bottles, and was practically without breakage. On changing in the reverse direction, breakage did occur, but there is little, if any, reason for a sudden drop of such magnitude in actual use.

The bottles were grouped according to diameter, capacity, weight, ratio of weight to capacity, and shape, for the purpose of comparing the various tests. It is not possible to detail the results here but any bottle with a long sloping shoulder of the champagne type, having an even distribution of metal and being well annealed, is a strong type. These tests do not tell the whole story but they do serve as a starting point for future work.

A similar line of work was carried out with prescription bottles of various sizes from one-half to sixteen ounces, of the round, oval, square, and panel types. These bottles are obviously not as heavy nor as strong as the beverage bottle, as they are generally handled carefully and rarely have a re-use. The round type is distinctly the stronger, then follows in order the oval, square, and panel. These tests have a more important bearing in connection with bottles for patent and proprietary preparations which must stand shipping hazards after being filled, than upon the prescription ware which is passed from the druggist to the purchaser. The uneven distribution of glass due to square shoulders, sharp corners, flutes and panels, and irregularities in shape which permit excessive pressure on small areas in packing, help to make the difference between the non-fragile and the ware which needs the label "handle with care."

Experiments have also been carried on with corks or seals to determine their resistance to leakage, not merely liquid leakage but passage of gas as in the case of carbonated beverages or air in the case of still products. This naturally included jars and bottles subject to pasteurizing and sterilizing processes. One can now purchase closures which vary from those that will leak like a sieve, to those which will resist a pressure of more than 200 pounds.

The matter of the soluble alkalinity of glass has been receiving more attention recently than at any time in the past. Troubles from this source are of such rare occurrence that they receive undue notice because of that fact. It is probable that less than one-twentieth of one per cent of the articles packed are affected by free soluble alkali. American bottles are better in this respect than foreign ones, if the figures available admit of making a comparison.

Science came to the rescue of optical glass during the war. The results were marvelous. The manufacturers of common glass have taken notice and are applying in a small way the same line of attack to their problems, and as they produce results we may expect an extension of the work.

OBSERVATIONS ON THE FACTORY CONTROL OF FISH-SCALING[1]

By John S. Grainer

ABSTRACT

An analysis of fish-scaling, its causes and prevention, based upon observations and experience of practical work. Three principal causes of fish-scaling are: (1) Improper firing, either underfiring or overfiring, especially the latter since its effects are usually not evident until the ware is finished and marketed; (2) The use of a clay which does not give a free running uniform coat without the use of excessive amounts of flotation agents. Clays which, when stirred up with water give a persistent suspension are recommended. (3) Improper type of furnace for the firing operation. The author prefers the open type furnace for the firing of enameled ware.

To the uninitiated, the cause and control of fish-scaling seems of very easy solution, but to those familiar with enameling operations it is a serious question and a matter of vital importance; for unfortunate is the enameler whose ware is suffering from an aggravated case of this troublesome pest. So many causes have been attributed to it, and it occurs under so many different conditions and stages, that one is at a loss to know from what direction to attack it. Among the causes which have been advanced are the following: improper smelting, character of clay, improper milling, character of iron, lack of regulation of the acid bath, type of furnace, underfiring, relative coefficient of expansion of enamel and steel and such a host of other causes that upon investigation we rarely find two enamelers holding the same opinion.

Of the above causes, underfiring, character of clay and type of furnace, are the ones selected by the writer for a brief discussion. The remaining causes appear to be of secondary consideration. Still at times the writer is tempted to believe that the character of the iron may be an important factor. Nor can we ignore the fact that the established law of expansion and contraction holds an important place, being held by many as the

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[1] Received August 18, 1921.

primary cause, not so much in its action alone but through other contributory causes that tend to rupture the enamel during the expansion and contraction of the ware. The glass maker has been successful in controlling this situation by the manipulation of materials and conditions until it is possible to expose certain glasses to extremes of heat and cold without fear of rupture. The enameler of cast iron has also been highly successful in this respect. But the enameler of sheet steel has not been as fortunate and his inability to definitely explain the phenomena has made him a target for criticism.

Taking up the first subject for discussion, that of underfiring, the writer believes that one of the principal causes of fish-scaling of finished ware is not so much underfiring as overfiring. An experienced burner can detect a piece of underfired ware quicker and with more certainty than he can tell a piece that has been overfired. For the writer knows of no rule to determine whether a piece, that to all appearances has been properly burned, will fish-scale or not until the trouble actually manifests itself.

This brings forth the question as to what change or action takes place from overfiring. If we should apply a uniform coat of enamel frit or glass that had been finely milled without clay to a piece of sheet steel and burn it, we would find upon withdrawing it from the furnace that its high luster and pleasing appearance apparently make an ideal coating; but after it is cooled we are not surprised to see the coating shivering off of the piece until the metal is bared, due to the absence of clay. On a second piece we repeat the operation but add clay in the mill and after burning and cooling the shivering has ceased or diminished according to the percentage of clay added. We will proceed to refire the piece containing the clay without recoating it and subject it to the intense heat generally used in ground coat burning and we find that if overfiring has taken place, one of three conditions are present—either the ground coat is sintered; the iron scale has forced its way through the enamel; or the ground is burned to a greenish brown color. Here the writer claims the damage is done, as the prolonged intense firing has destroyed or changed, either entirely or in part, that property of the clay that tends to regulate the gravity of the enamel until we find after burning nothing is left on the ware but the ground frit or glass minus the clay, or essentially the same conditions we had on the piece that shivered off.

Fish-scaling from underfiring generally takes place upon the cooling of the ware or within a few hours after burning and it is the contention of the writer, based on factory observation, that the scaling from overfiring while not so conspicuous or prominent as the former is nevertheless just as persistent and does not occur until a few days up to two or three months after the ware is finished. As the ware is generally white coated the same day or the day following, it can be readily understood how very easily it is possible to overcoat a condition of fish-scaling that will not manifest itself until it is on the market. To white coat a piece of underfired ware that looks suspicious is simply inviting disaster from which the enameler cannot escape; but until some definite rule or means are discovered to also avoid the overfired piece we can only hope to follow the beaten path of taking chances.

There is no question but that pieces of underfired ware will at times pass unnoticed through the various operations and find their way to the market, but the amount of fish-scaling one sees in the display windows of various cities, both on stove, hollow ware and refrigerator works, is *prima facie* evidence that it is not all due to underfiring for the amount is too great to pass unnoticed if underfired. Therefore, we can reasonably suspect that it is due to the fact that the ware had been overfired and that the retarded scaling resulting therefrom did not manifest itself until after the ware was on the market.

In considering the second cause of fish-scaling, namely that of clay, the writer believes that herein lies the most important factor entering the enameling of sheet steel. The pride of every enameler is a reliable ground coat formula which he regards as his most treasured possession, and rightly so, for herein lies the secret of his success. We can expect that his ground coat, if properly used, will not fish-scale. The term "properly used" in this case simply means that the clay used is of the right character to make possible proper slushing and burning of the ware.

In discussing the effect of overfiring, we alluded to a particular point at which the efficiency of the clay was destroyed; remembering this point, we must select a clay that will still retain its efficiency at the higher temperatures. Still another and more important requisite, is the selection of a clay that will hold the frit in suspension without the excessive use of flotation agents. An enamel ground coat applied too thinly, and fired too hard will fish-scale and enamel applied too heavily and underfired will do the same. On irregular shaped ware that has been dipped or shaken out, or on pieces on which the ground is required to flow from different angles, it becomes almost impossible to apply a uniform coating. Consequently upon firing we have two extremes to overcome at the same time. If we overfire the one part we underfire the other—hence, the importance of a free running clay that will insure a uniform coat on all parts of the piece. The non-uniform condition of the ground coat is very often the cause of fish-scaling on certain areas of the ware.

In selecting a clay the writer has used a very simple but satisfactory method of testing the ability of the clay to remain in suspension. Six one-quart Mason jars were procured, also samples of six of the leading well known American and foreign clays, regardless of their chemical analysis or prestige. Into each jar one pound of clay was placed and the jar filled with water. This was allowed to stand a few days until the clays were thoroughly saturated, after which they were all stirred by hand as quickly as possible and were then allowed to stand one week, after which the following data were noted. Four of the clays settled to the bottom of the jars in six hours, some more compactly than others. One, a washed clay, while not settling very fast, gave evidence of being held in suspension by the addition of some chemical agent. The remaining clay settled about one-half inch and remained so until the water was entirely evaporated from the surface, a matter of thirty days' time. This one showed no evidence of being chemically treated and was selected by the writer for further experiments for the reason that, if the other clays could not hold themselves in suspension, they certainly could not hold the frit. A batch of frit was then milled with ten per cent of this clay and the results were good. Suffice it to state that this clay was adopted.

The irregular shape and size of a refrigerator lining requires the entire immersion of the piece into a tank of ground coat of about one hundred and seventy-five gallon capacity. When the plant at which the writer is employed first started operation four years ago, it was very difficult to get a clay that would deposit the frit uniformly over the piece, consequently much fish-scaling appeared on the parts where the enamel was too thin or too heavy. With the changing of the clay and firing conditions corrected, this trouble has entirely disappeared. During the war the plant was obliged to shut down for a period of five weeks, the supply of fuel oil having been exhausted, and the writer was very much gratified upon returning to find the ground coat was still in a good state of suspension with very little precipitation at the bottom of the tank. Hence, we find from this that the flotation element of a clay holds a very important place in the occurrence of fish-scaling, as it not only makes it possible to apply a more uniform coat, but in a furnace of even heat distribution the firing is more uniform and more easily controlled.

The third and last cause of fish-scaling selected for discussion relates both to firing and the type of furnace used, and while it appears the last for discussion, it is by no means the least, for the results of our attention or our inattention to the details leading up to the firing operation will be indelibly engraven on the surface of the piece after firing. The old adage that "a poor workman will kick on the tools" is at times only too true. But after viewing some of the furnaces in different plants the writer is convinced that the workman often is justified in his "kicks." No matter how carefully details have been accounted for up to the firing operation, the labor will be in vain unless the means for proper firing conditions have been considered. The industry is awakening to this fact and as a consequence many new types of furnaces are being introduced, and while the intermittent firing open type furnace is not of recent origin it is now rapidly displacing the muffle type in many plants for the following reasons: It has a more uniform distribution of heat which insures the uniform firing of all pieces of ware, thus reducing the risk of over- or underfiring; as the firing is discontinued while the ware is at high heat, economy in fuel is obtained. Its solid construction of standard fire brick minus special forms adds to its life thereby reducing the upkeep and making possible the firing of the ware without deformation of the muffle. Added to this advantage, its complete absence of gas makes it an ideal furnace. What relationship exists between fuel gas and fish-scaling, if such does exist, is not known. That its effects are injurious to the enamel cannot be doubted by the appearance of the disagreeable bluish color imparted to the ground when fired in a furnace containing gas. That there is a difference in ware burned in a muffle type of furnace and in the open type is beyond doubt. The fact that the muffle type is very seldom free from gas due to leaky joints or defective flues, while the open type is entirely free from gas gives strength to the opinion of many that the action of gas is a contributing cause of scaling.

Another important condition often overlooked in firing the ware is that the ground coat is applied too thinly and fired too hard. The fault does not lie so much in the length of time consumed but more in the severe high temperatures carried, no provisions being allowed the ground coat for the subsequent firing of the white. This is especially true of samples of hollow ware examined, for upon breaking through the white, one will find scarcely any traces of the ground. The result is that what anchorage the white depended upon from the ground has been destroyed by overfiring, a condition which later may cause fish-scaling or which will not permit the abuse to which the ware will be normally subjected.

The writer has long held the opinion that all sheet steel enamels could be so formulated as to lower their firing temperatures so that after firing, the ground remained intact. While this may not be possible on hollow ware, owing to the hard acid-resisting whites used, this rule can be applied to stove, refrigerator and kindred lines and would result in more shapely and durable ware.

In conclusion, the writer would state that the plant in which he is at present employed is in the fourth year of its production. During the first two years in which the muffle type of furnace was used the firm was about convinced that it had an unwelcome monopoly on fish-scaling and years of past experience availed naught in correcting the trouble. Every source from which it might originate was thoroughly investigated and from the conclusive evidence of the results obtained the causes were traced to the three conditions under discussion, namely, overfiring, clay, and furnace construction. An open type furnace was installed, firing conditions corrected and the ground coat so formulated as to mature at lower temperatures. A clay was selected that would hold the frit well in suspension without the excessive addition of flotation agents, while a more uniform application of the ground coat was produced. In the last two years, since the change was made, with the exception of an occasional piece that could be readily traced to underfiring, all pieces have been free from fish-scaling.

Not on any one of the conditions alone depends success but on the three combined. A successful furnace will not produce satisfactory results unless the dipping or slushing conditions have been properly controlled and this in turn cannot be made possible without the use of the proper clay. Yet it is very evident that if the three conditions are carefully regulated the general result will promote success.

Grand Haven, Mich.

PHYSICAL DEFECTS IN TANK BLOCKS[1]

By Geo. A. Loomis

ABSTRACT

An investigation of some of the leading makes of tank blocks of flux grade tends to show that these blocks as a class, are not as free of physical defects, such as fissures and lamination, as could be desired. Photographs are shown of representative sections of the blocks examined.

Physical defects in tank blocks, such as fissures and lamination, especially in the so-called flux grade, are generally conceded to be detrimental to the life of these blocks in service, and hence, to the life of the tank, since the glass more readily penetrates and attacks the blocks when such imperfections are present.

An investigation, made by the writer about two years ago, in the interests of the Corning Glass Works, Corning, N. Y., and which included some of the leading makes of flux blocks, indicated that such blocks, as a rule, were not as free of physical defects as could be desired. The blocks included in the investigation were made during the war period and were said, by some of the manufacturers, to be below their usual standard in freedom from defects. Recently-made blocks of some of the same makes have, however, shown but little, if any, improvement in this respect. The data obtained in the investigation mentioned is, therefore presented herewith to point out the need of improvement.

The investigation was made as follows:

Three blocks were selected at random from carload shipments of each of three makes. One block was likewise taken from a small shipment of another make. These blocks were carefully cut up into sections about three inches thick by cutting all around the block with a broad chisel until the section became detached from the balance of the block. In all but one or two instances, these sections were removed intact. Whenever a loose "sliver" remained attached to the section, it was carefully removed to avoid

[1] Received Nov. 21, 1921.

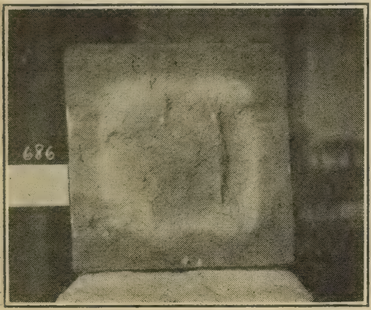

FIG. 1.—Representative section of Block No. 1, Make No. 1.

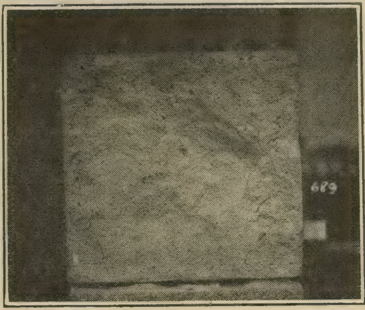

FIG. 2.—Representative section of Block No. 2, Make No. 1.

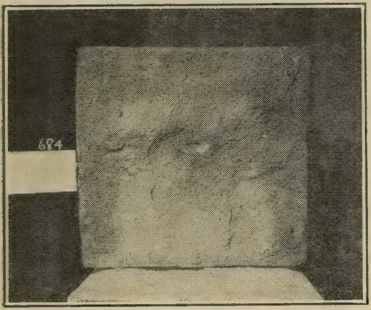

FIG. 3.—Representative section of Block No. 3, Make No. 1.

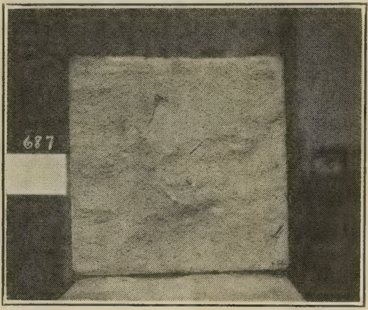

FIG. 4.—Representative section of Block No. 1, Make No. 2.

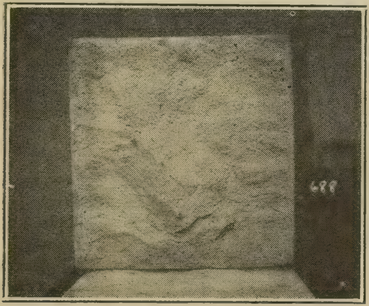

FIG. 5.—Representative section of Block No. 2, Make No. 2.

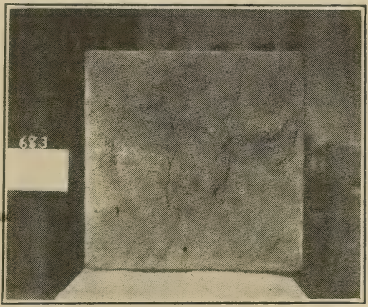

FIG. 6.—Representative section of Block No. 3, Make No. 2.

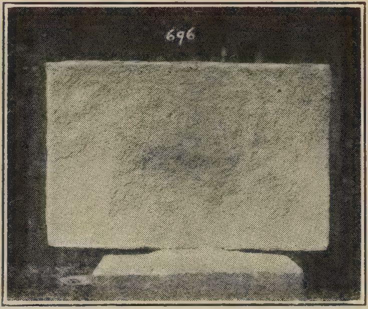

FIG. 7.—Representative section of Block No. 1, Make No. 3.

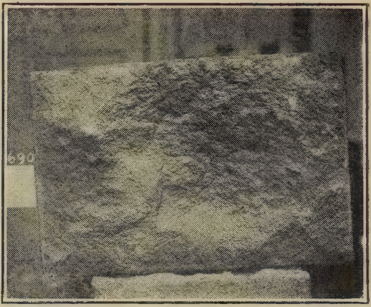

FIG. 8.—Representative section of Block No. 2, Make No. 3.

FIG. 9.—Representative section of Block No. 3, Make No. 3.

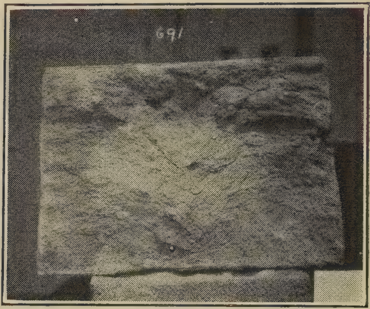

FIG. 10.—Representative section of block of Make No. 4.

mistaking it for an imperfection. Each section was then carefully examined and note taken of the size and number of fissures and other defects present. A photograph was taken of a representative section of each block.

The observations made in the examination of the various blocks were as follows:

Block No. 1, Make No. 1.

1st section: One fissure 3″ by $^1/_{32}$″; three or four fissures $^1/_2$″ by $^1/_{16}$″; quite a number of small pin holes.

2nd section: One hair-line crack 2″ long; six or eight small holes about $^1/_{16}$″ in diameter; quite a few pin holes and small cracks.

3rd section: Two fissures, $^1/_{16}''$ by $^3/_4''$; five or six holes $^3/_{32}''$ in diameter; one hair-line crack $1''$ long; many small pin holes.

4th section: Four fissures, $1''$ to $1^1/_2''$ long by $^1/_{32}''$; two holes $^1/_8''$ in diameter; quite a number of small checks and pin holes.

5th section: Six fissures $^3/_4''$ to $1''$ long by $^1/_{16}''$ wide; a considerable number of pin holes.

6th section: One fissure, $3''$ by $^1/_8''$; one hole, $^1/_4''$ by $^3/_4''$; another, $^1/_8''$ by $^1/_2''$; another, $^1/_4''$ in diameter; two or three fissures, $1''$ by $^1/_{16}''$; quite a few pin holes.

It will be noted in the representative section, shown in Fig. 1, that this block also shows evidence of being improperly burned.

Blocks No. 2 and 3, Make No. 1.

The defects noted in the various sections of these two blocks were very similar to those noted in block No. 1. Representative sections of these blocks are shown in Figs. 2 and 3, respectively.

Block No. 1, Make No. 2.

1st section: One fissure $8''$ long by $^1/_{32}''$ wide; three $1^1/_2''$ to $2''$ by $^1/_{32}''$; two holes $^1/_8''$ to $^3/_{16}''$ in diameter; many small pin holes.

2nd section: One fissure $6''$ long, $1^1/_2''$ of which was $^3/_{32}''$ wide, and the remainder $^1/_{32}''$; two fissures $2''$ by $3/_{32}''$; two holes $^1/_8''$ in diameter; quite a number of small checks and pin holes.

3rd section: Five fissures $1''$ by $^1/_{32}''$; two $2''$ by $^1/_{32}''$; one hair-line fissure $3''$ long; one irregular hole $^1/_4''$ in diameter; quite a few pin holes.

4th section: One fissure $3''$ by $^1/_{32}''$; one hair-line fissure $4''$ long, and another $2''$; one fissure $1''$ by $^1/_8''$ to $^3/_{32}''$; three or four $^1/_2''$ by $^1/_{16}''$; a number of pin holes.

5th section: One fissure $6''$ by $^1/_{16}''$; two $1^1/_2''$ to $2''$ long by $^1/_{32}''$; several small checks and pin holes.

6th section: Several hair-line fissures $2''$ to $3''$ long.

A section of this block is shown in Fig. 4.

Blocks No. 2 and 3, Make No. 2.

The size and number of defects in these blocks were much the same as those in No. 1 of this make. Figs. 5 and 6 show representative sections of these blocks.

Blocks No. 1, 2 and 3, Make No. 3.

Not a fissure or other defect could be discovered in any section of these blocks. All three blocks showed a very compact structure throughout. Sections of these blocks are shown in Figs. 7, 8 and 9. No. 2 block (Fig. 8) was red in color and shows dark in the photograph so that the actual lack of any defect is not very apparent.

Block of Make No. 4.

An average section of this block is shown in Fig. 10. Each section showed much lamination with many fissures, some of them being 3″ to 4″ long and 1/4″ wide; also numerous small checks and pin holes.

It will be observed from the foregoing data that physical defects were present to an objectionable extent in all but one of the makes examined. As already stated, recently-made blocks of some of the same makes have been observed to be defective to practically the same extent, and inasmuch as some of these makes are considered among the best on the market, it would appear that there is in this respect, room for considerable improvement in flux blocks as a class.

The fact that all of the blocks of one of the makes examined showed a total absence of fissures, lamination and other defects would seem to indicate that the maker of these blocks has found a method of eliminating such imperfections. At any rate the specimens examined show that it is possible to produce tank blocks entirely free of these defects. It would, therefore, seem that the blocks of other makes could at least be materially improved in this respect.

It is not intended, in this paper, to suggest a method of eliminating these defects. It might be stated, however, that, judging from appearances, closer supervision of the molding by the present method would, in some cases, materially reduce the number of badly defective blocks.

WASHINGTON, D. C.

EFFECT OF WEATHER UPON THE STRENGTH OF REFRACTORY BRICK.[1]

By R. M. Howe, S. M. Phelps, and R. F. Ferguson[2]

ABSTRACT

Magnesia and silica brick should be protected from the action of the weather.

Open textured fireclay brick (usually having end cold crushing strengths of less than 1500 pounds per square inch) should be afforded protection from the action of the weather.

Finely ground, dense, hard-burned firebrick, especially those of medium or low refractoriness, may be exposed to the action of weather with a reasonable amount of safety. These are usually made from one clay which is shaped on a dry press or auger machine and have an end cold crushing strength approximating 5000 pounds per square inch.

Introduction

In many cases extreme care is exercised in the storage of refractory bricks to protect them from the action of the weather. At certain plants kilns of magnesia brick are not unloaded in rainy weather. In other instances bricks are given little or no protection from the action of rain or even snow. While good practice would favor careful storage, it should be remembered that clay bricks are used for paving and building and undergo very little deterioration due to the action of the weather.

Inasmuch as there were no definite data as to the effect of weather, the tests herein described were started December 15th, 1919, in order to secure definite information on the subject.

Materials Used

Fireclay, silica and magnesia brick were purchased in the open market for use in this test. The fireclay bricks of type "A" were made from semi-flint clay and were of first quality

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[1] Received Nov. 24, 1921.

[2] Contribution from the Refractories Manufacturers Association Fellowship, Mellon Institute of Industrial Research, Pittsburgh, Pa.

refractoriness. The fireclay bricks of type "B" were made of about 80 per cent of flint clay and bats bonded with 20 per cent of plastic clay. The silica brick were typical open-hearth and by-product coke-oven brick. The magnesia brick were representative machine-made brick, such as are used in the metallurgy of iron, steel, and copper. The analyses are presented in Table I.

TABLE I

ANALYSES OF REFRACTORY BRICK EXPOSED TO WEATHER

Kind of refractory brick	Fireclay brick "A"	Fireclay brick "B"	Silica brick	Magnesia brick
Silica	50.98	55.02	96.58	7.80
Alumina	43.94	39.89	.74	2.42
Ferric Oxide	3.16	3.63	.50	3.62
Lime	.36	.86	1.88	3.86
Magnesia	.52	.26	.16	82.40
Alkalies	1.32	.79	.21	trace
Total	100.28	100.45	100.07	100.10

Method of Exposure.[3]

The bricks were piled on the ground about 10 high in a wire pen which was open at the top and protected on only one side (see Fig. 1). Samples were reserved for testing and the rest were stored for 3, 6, 9 and 12 month periods. Care was exercised at the expiration of these intervals to secure specimens from the top, center, and bottom of the pile.

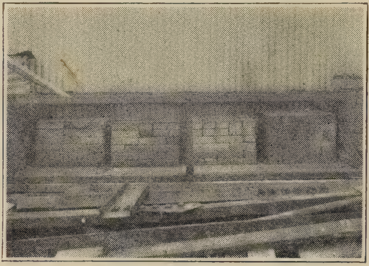

FIG. 1.—Method of exposing refractory brick.

Method of Testing

Only a few kinds of tests were applied so that a greater number of samples would be available for each and because weather could not seriously affect many of the characteristics usually determined. It might, however, lower their mechanical strength and thus decrease their resistance to abrasion, resistance to spalling, or crushing strength. Consequently, cold crushing tests were applied to each set of samples, selecting from six to eight in each case. It can be assumed that, with a given lot of brick, the resistance to abrasion and impacts, the strength in arches, and the strength under load at high temperatures would vary with the cold crushing strength.

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[3] The weather during the period was typical of Pittsburgh, Pa.

This is also true for the resistance to spalling when one particular lot of bricks is under consideration. While thermal expansion, vitrification, grind and burn all have a relationship to spalling, these characteristics are constant for each brand and so the most important variable that might enter in this case appears to be a possible decrease in the strength of the bond. Spalling tests were made upon the fireclay brick, although they were omitted with the magnesia and silica brick because of the difficulty of obtaining significant results with these two types.

The spalling tests with the fireclay brick consisted in heating the specimens in the door of a furnace operating at 1350°C, partially immersing in a trough of running cold water for three minutes, air-drying, and repeating in hourly cycles. The bricks under consideration were particularly well bonded and hence the tests were discontinued after 25 partial immersions.

Results of Cold Crushing Tests

The figures given in Table II are expressed as end cold crushing strengths in pounds per square inch.

The average values are taken from six to eight determinations, a few of the results having been discarded when they showed abnormal deviation from the average.

TABLE II

END COLD CRUSHING STRENGTHS OF REFRACTORY BRICK AFTER EXPOSURE

Type		As received	After 6 months	After 12 months
	Maximum value	1418	1404	1109
	Minimum value	782	855	891
Fireclay A	Average value	1127	1114	1005
	Per cent average deviation	22.8	13.4	9.3

END COLD CRUSHING STRENGTHS OF REFRACTORY BRICK AFTER EXPOSURE

Type		As received	After 6 months	After 12 months
	Maximum value	1355	909	755
	Minimum value	545	545	545
Fireclay B	Average value	885	693	640
	Per cent average deviation	26.9	20.5	10.1
	Maximum value	2727	2245	1418
	Minimum value	1373	1327	909
Silica	Average value	1830	1680	1111
	Per cent average deviation	23.1	17.7	17.5
	Maximum value	5582	4255	3914
	Minimum value	3273	2726	2082
Magnesia	Average value	4464	3780	2978
	Per cent average deviation	14.5	12.7	17.4

Results of Spalling Tests

The following results also represent an average. It should be noted, however, that the bricks tested were unusually well bonded. This condition was not anticipated and the series should also have included bricks which fail after five, ten, and twenty immersions.

TABLE III

PER CENT SPALLING LOSS OF A AND B FIREBRICKS AFTER EXPOSURE AND 25 IMMERSIONS IN TEST

	As received	After six months	After twelve months
A	17	16	40
B	10	22	33

Discussion of Results

The crushing strength of the magnesia bricks decreased 15 per cent in six months and 33 per cent in twelve months. This decrease can safely be interpreted as representing still greater decrease in resistance to abrasion, construction stresses and spalling. When the original bricks were compared in the load test under a pressure of 25 pounds per square inch with those which had been weathered for 12 months, the latter sheared at a temperature about 40°C lower. The magnesia bricks underwent the greatest percentage loss in strength,—a fact which explains the practice of protecting them carefully from the weather.

The decrease in the strength of the silica bricks was rather unexpected for they showed no outward signs of deterioration. Nevertheless, they lost 39 per cent of their original strength during the 12-month period. This condition is equally as, or more serious than, is the case with the magnesia bricks, for one of the greatest assets of silica bricks is their high strength, especially at working temperatures.

The fireclay bricks lost from 1 to 21 per cent in cold crushing strength after six months and from 11 to 28 per cent after twelve months. Additional samples of a third very strong brand of machine-made firebrick (C) were secured after six months. They had an original end crushing strength of over 5,000 pounds per square inch and showed practically no loss in strength after six months' exposure. On the other hand, some open porous hand-made bricks having an end crushing strength of only 500 pounds per square inch were practically worthless after six months' storage at a plant.

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POROSITY: VI. DETERMINATION OF POROSITY BY THE METHOD OF GAS EXPANSION *

By Edward W. Washburn and Elmer N. Bunting

ABSTRACT

Theory of the method.—The pore volume is measured by allowing the gas which fills the pores to expand into a measured volume and measuring the accompanying fall in pressure.

Applicability.—The method is in general applicable to pieces of any size and shape and to all classes of porous bodies or materials.

A new porosimeter.—For rapid work with shaped test pieces a new porosimeter is described. The new instrument measures accurately both pore volume and bulk volume. A complete porosity determination can be made in 5 minutes. No weighing is required. The results on ceramic bodies are reproducible to one unit in the first decimal place of the per cent porosity. Considerably higher accuracy than this can be secured if desired.

Results.—The results obtained with the new method are in all cases higher, in a number of cases very much higher, than those obtained by the methods of liquid absorption in current use. For fired bodies the same results are obtained with dry air, hydrogen or helium as the pore filling gas. The results show conclusively that complete filling of all the pores in a reasonable time can not be secured by any of the current methods using a liquid as the pore filling agent.

XVI. Introduction

53. Theory of the Method.—In the method described in the present paper a gas instead of a liquid is employed as the pore filling agent and its amount is determined by measuring the fall in pressure which accompanies a definite increase in its volume.[38] Owing to the low viscosity of gases this method is capable of yielding accurate results even for bodies with exceedingly fine pores where the liquid-absorption method either fails or requires recourse to high pressure apparatus. The new method possesses none of the drawbacks or sources of error of the liquid-absorption methods and in addition possesses a number of marked advantages of its own. The degree of accuracy attainable is greatly in excess of any practical requirement of ceramic testing.

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* Presented before a meeting of the Ohio Section, in Columbus, Nov. 19, 1921.

[38] The principle of this method was employed by Zehnder [*Ann. Phys.*, **10**, 40 (1903) and **15**, 328 (1904)] in an effort to perfect a rapid method for determining the true density of a material. For this purpose the results were not satisfactory from the point of view of accuracy. The extension of the method to the determination of porosity is of course obvious but does not seem to have been made heretofore.

54. Applicability of the Method.—The method is in general applicable to pieces of any shape or size, including granular material, and to all classes of porous bodies or materials whose bulk volume can be determined. Since no absorption liquid is employed, the piece under investigation is not injured or altered in any way during the determination. The method could thus be safely employed for determining the porosity of pieces of art pottery, archeological specimens or materials which might be injured by absorption liquids.

Two procedures will be described. The first one, which will be called the *General Method,* is applicable to pieces of any size or shape but is not so rapid as, and requires somewhat more elaborate apparatus than, the second method. The second method, which will be called the *Rapid Method* is designed for *shaped test pieces* and for rapid measurements in the laboratory or works.

XVII. The General Method

55. Apparatus and Procedure.—A flask or other suitably shaped vessel, B, of volume, V_1, is joined, by a capillary tube carrying a stop-cock, to the test vessel A, of volume V (see Fig. 7). To the vessel A is also attached a suitable manometer for measuring the pressure. The weighed piece or sample (W grams) of the dry material is placed in vessel A and, if maximum accuracy is required, the remaining unfilled portion of vessel A is filled with glass beads or rods of density D_g and mass m_g. The vessel A is then evacuated to some low pressure $P_\circ$ (*e.g.*, 20 mm. Hg).

Flask B is filled with a non-adsorbable gas under suitable pressure. For most ceramic bodies dry air is a satisfactory gas but hydrogen will be required in some instances. (*Vide infra*, Sec. 69.) Helium could, of course, be employed for *all* types of porous materials at room temperatures or above. If a gas other than air is used, the vessel A and the pores of the material under investigation must first be filled with this gas before evacuating vessel A to the pressure P_0.

The whole apparatus is now allowed to stand (preferably in a constant temperature bath, if maximum accuracy is desired) until temperature equilibrium is attained. The vessel B is then opened momentarily to the atmosphere in order to secure atmospheric pressure within it and is then closed again. When com-

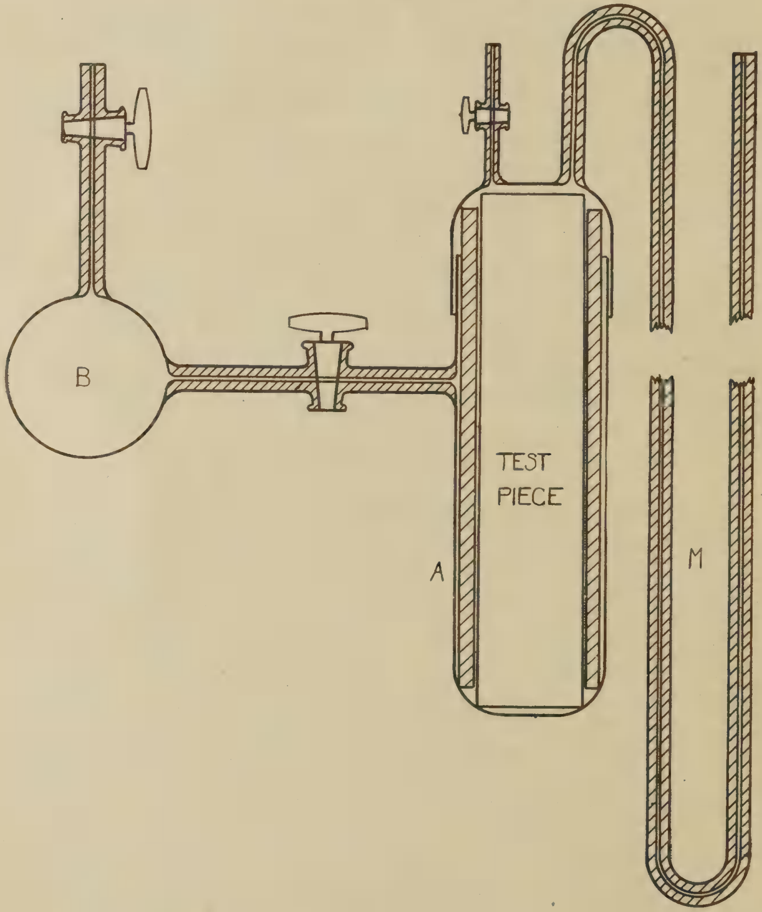

Fig. 7.—Porosimeter, general type.

plete temperature equilibrium is attained the manometer is read $(P_\circ)$ and the stop-cock connecting the two vessels is then opened. When equilibrium is again attained the manometer is again read, P. The per cent porosity x can then be calculated from the relation

$$x = 100\left[\frac{(B-P)\ V_1}{(P-P_\circ)\ V_B} - \frac{V - m_g D_g - V_B}{V_B}\right] \tag{14}$$

The bulk volume V_B, if not determined directly on the sample or piece used, is calculated from the relation $V_B = \frac{W}{D_B}$.

The functioning of the manometer should not appreciably affect the volume of the vessel to which it is attached or else the necessary correction should be applied. The method could obviously be used with the manometer attached to either of the two vessels and, if desired, the evacuation might be applied to vessel B instead of to vessel A. The formula for any of these arrangements and procedures is readily deducible from the gas laws.

56. Precision of Measurement and Principles of Design.—The best volume for the vessel B is that given by the expression

$$V_1 = \frac{100(V - m_g D_g) + (x-100)\ V_B}{100} \tag{15}$$

and under these conditions

$$P = \frac{B + P_\circ}{2} \tag{16}$$

For a given sized test piece the accuracy of the measurement increases as the unfilled space in vessel A decreases. This is the reason for filling the space around the test piece with glass rods or beads as far as possible.

If the volume measurements are accurate to 0.01 cc. and the pressure measurements to 0.2 mm. of mercury, the total error in x will not exceed 0.1 unit for porosities up to 30 per cent and will not exceed 0.2 unit for higher porosities. Greater accuracy can be secured, if required, by proper design and care in measurement.

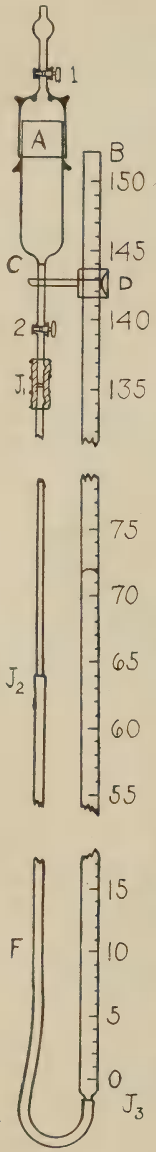

FIG. 8.—Rapid porosimeter.

Some control of temperature is essential for the most accurate work. Thus a variation of 0.5° in temperature between the initial and final pressure readings will produce an error of only about 0.1 unit in the computed porosity provided P_0 is not greater than about 20 mm. of Hg.

XVIII. The Rapid Method

57. The Apparatus.—A special apparatus called a *porosimeter* has been designed for rapid porosity determinations by the gas expansion method. The apparatus is designed primarily for use with shaped test pieces and is at the same time a simple and accurate volumeter and expansimeter. The bulk volume and the pore volume of the test piece are both directly measured and no weighing is required in any stage of the process.

The complete porosimeter is shown in Fig. 8. It consists of the porosity bulb A, connected by an impervious rigid walled flexible tube, F, to the burette B, which is provided with a movable reading arm, D. The burette tube is of uniform bore and is accurately graduated in *centimeters and millimeters.* Its internal cross-section should preferably be chosen so as to be close to one square centimeter or some even multiple or submultiple thereof.

58. Porosity Bulb Detail.—The details of the construction of the porosity bulb are shown in Fig. 9. This bulb consists of a vessel just large enough to admit an unfired test piece of standard dimensions. The hooks on the outside allow the cap to be held tightly in place by means of rubber bands or spring clamps. The small projections on the inside of the cap are for the purpose of preventing the closure of the outlet tube by the test piece as it is lifted by the admission of the mercury.

The cap and both stop-cocks must be well ground and fitted so that the bulb will hold a vacuum for at least 15 minutes without leakage greater than the equivalent of 0.1 mm. of mercury.[39] For bulk volume measurements only, where the highest accuracy is required, the porosity bulb may be provided with the side tube 3, for convenience in drawing off mercury. For most ceramic testing. however, this side tube is an unnecessary complication.

The piece R (Fig. 9) is a solid glass rod, called the *reference piece*, whose volume V_R, is accurately determined by weighing it suspended in a liquid. Its purpose is explained below.

59. Setting up the Apparatus.—Clean the porosity bulb and burette with chrome cleaning mixture and dry. Lubricate all ground joints.[39] Connect the apparatus as shown in Fig. 8, and wire each connection tightly. Place the bulb and burette in their supports. Place in the porosity bulb the reference piece, R, whose volume V_R, is equal to $(1-s)V_d$ where V_d is the bulk volume of the test piece for which the porosity bulb is designed (cf. Sec. 67) and s is the maximum fractional shrinkage which must be provided for. Place the cap on the porosity bulb and secure it. Then raise the burette until its zero mark is on a level with stop-cock 1 (Fig. 9). Open both stop cocks and pour clean mercury into the burette until the porosity bulb is full. Manipulate the apparatus until all bubbles of air caught between mercury and the tube wall have been removed.

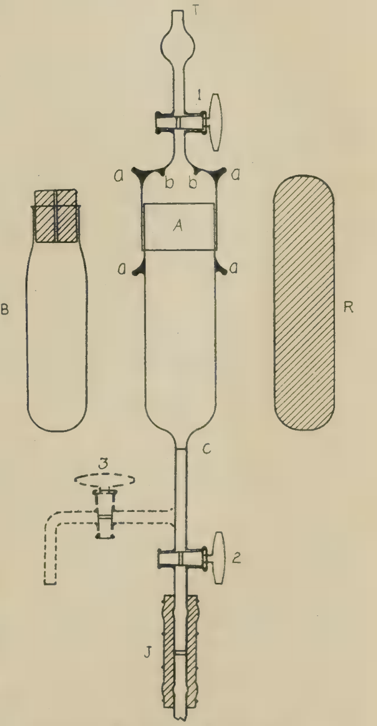

FIG. 9.—Porosity bulb detail.

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[39] The sealing varnish and the lubricant previously described (see footnote 34) may be used as needed at these ground joints.

60. Determination of the Volume of the Porosity Bulb.—This determination, which needs to be made only once for a given apparatus, is conveniently carried out as follows: With the reference piece in place and both stop-cocks open, raise the burette until the mercury just fills the porosity bulb up to and into stop-cock 1. Close both stop-cocks and lower the burette until the mercury surface is approximately level with mark C (Fig. 9). Read the burette, R_1. Open stop cock 2, and lower the burette until the mercury level in the porosity bulb coincides with mark C. Close stop-cock 2 and raise the burette until the mercury surface is again approximately level with mark C. Read the burette, R_2. The difference between the two burette readings, R_2-R_1, is the free volume V_F, of the porosity bulb when the bulb contains the reference piece.

Open stop-cock 1 and remove the reference piece. Open stop-cock 2 and again raise the burette until the mercury level stands approximately at its zero mark. Close stop-cock 2, lower the burette until the mercury surface in it is on the level of mark C and read again, R_3. Now pour out the mercury in the porosity bulb until the level falls to mark C. Collect and weigh this mercury,[40] m_m grams.

The volume V, of the porosity bulb may now be computed, in burette-scale units, from the relation

$$V=V_F+\frac{V_R(R_2-R_3)\,D_m}{m_m} \tag{17}$$

where D_m is the density of mercury at the room temperature prevailing.

61. Determination of the "Effective Barometric Pressure."—The "effective barometric pressure" B, is a quantity which is constant for a given piece of apparatus but is a function of the actual barometric pressure of the locality at the time the apparatus is being used. A value once determined can be employed as long as the barometer is constant. The determination is made as follows: Place the reference piece in the porosity bulb and secure the cap in place. With both stop cocks open, raise the burette until all the air is driven out of the porosity bulb. Close stop-cock 1.

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[40] If the porosity bulb is provided with the side tube 3 (Fig. 9) this mercury can be more conveniently drawn off through this tube.

Lower the burette until the mercury level in the bulb stands at mark C. Clamp the burette, set the reading arm on the level of the mercury surface at C and read its position on the burette, R_c. Then read the position of the mercury surface in the burette, R_m.

$$B=R_c-R_m \tag{18}$$

It is evident that the determination of the effective barometric pressure is almost as simple an operation as reading an ordinary barometer. For a given bulb it differs from the true barometric pressure of the locality by a substantially constant amount of about a millimeter. This small difference, which is made up of the capillary pressure at C plus the pressure of a small amount of adsorbed air given off from the walls of the porosity bulb, cancels out in the numerator of equation (14), since the same effects are present to substantially the same extent in the subsequent operations with the test piece in place. In the computation, therefore, this "effective barometric pressure" should be used rather than the actual barometric pressure.

62. Preparation of the Test Piece.—The dried test piece is trimmed with a knife to the size for which the porosity bulb is designed, or until its dimensions are such that on burning it will shrink to this size or smaller.[41] After burning, it should be cleaned and trimmed as directed in Sec. 43. Unless the test piece has been in contact with water or with very damp air it is not necessary, with burned ceramic bodies, to dry the test piece previous to making the determination.

63. Determination of the Porosity.—With the test piece in place raise the burette until the mercury fills the porosity bulb up to some point within the bore of stop-cock 1. Read the burette, R_0. Then proceed exactly as in the determination of the effective barometric pressure. Before taking the final pressure readings, which will now be called R'_c and R'_m, wait until these readings have become constant, adjusting the burette from time to time as may be necessary to make the mercury level in the bulb coincide with mark C. With most ceramic bodies equilibrium will be attained in two or three minutes, but with certain bodies, containing a considerable volume of micropores, as much as 30 minutes may be required. If the mercury level at C remains constant for 3 minutes equilibrium may be assumed to have been attained and the final adjustment and readings may be made.

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[41] If the porosity bulb is cylindrical in cross-section, somewhat greater accuracy can be secured in some instances (*Vide infra,* Sec. 67) by using test pieces with approximately octagonal cross-sections, which can be conveniently produced by shaving off the edges of the ordinary rectangular briquette after drying. For most practical purposes, however, the usual rectangular briquette will be quite satisfactory.

When R'_c and R'_m have been determined close stop-cock 2 and raise the burette until the mercury level in it is approximately level with mark C and read the burette, R.

If the walls of the flexible tube F (Fig. 8) are not compressed appreciably by the varying heights of mercury attained during the measurements

$$R = R'_m = R_m \tag{19}$$

and the determination of R and R'^m may be omitted. With a properly constructed flexible tube this will be approximately the case and for most practical purposes only the readings $R_\circ$ and R'_c need be made. In any case if the relation (19) is found to be approximately but not exactly correct, small correction factors (which will be functions of the porosity) can be determined for each apparatus containing a given quantity of mercury and applied to the reading R_m in order to obtain R'_m and R thus obviating the necessity of making these two readings in each determination. The influence of these and all other small correction factors can also be eliminated by calibrating the whole apparatus as described in Sec. 65.

64. Calculation of the Porosity.—The per cent porosity is computed from the relation

$$\frac{x}{100} = \frac{[B - (R'_c - R'_m)](R - R_\circ)}{(R'_c - R'_m + \Delta)\ [V - (R - R_\circ)]} \tag{20}$$

The small capillary depression correction, Δ, is a constant for a given apparatus and may be determined as follows: With both stop-cocks open raise the burette until the mercury stands at mark C. The difference in the two mercury levels is the quantity Δ. Repeat several times and take the average. If the porosimeter is calibrated, as described in Sec. 65, any uncertainty in the quantity Δ will be automatically taken care of by the calibration, and can have no influence on the result.

In equation (20) the quantity $R-R_\circ$, is the free volume, V_F, of the porosimeter and the quantity, $V-(R-R_\circ)$, is the bulk volume, V_B, of the test piece in burette scale units. If the porosimeter is provided with the side arm 3 (Fig. 9) these volumes can, if desired, be determined to a high degree of accuracy by drawing off the mercury through this side arm and weighing or measuring it. In that case the burette tube can be replaced by a simple leveling bulb and the pressures read by means of a cathetometer or a meter stick. (See Fig. 10.) This modified form of porosimeter construction while capable of somewhat greater accuracy requires more observations and more manipulations and is somewhat more expensive to construct. The simpler and more rapid form shown in Fig. 8 is therefore to be preferred for regular ceramic testing.

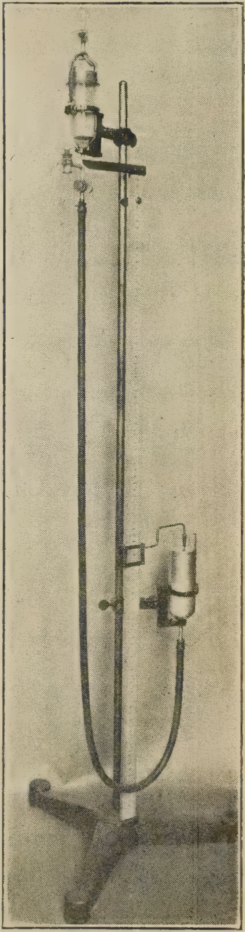
FIG. 10.

65. Calibration of the Porosimeter.—Like any other scientific measuring instrument the porosimeter should be calibrated over the region in which it is to be used, if results of the highest accuracy are desired. Calibration can also be made to take care of any uncertainty in the small Δ correction and of any small differences between R_m, R'_m and R, thus eliminating entirely two of the readings which would otherwise have to be taken during each determination (*Vide supra,* Sec. 63).

The calibration is made with the aid of the standard test piece B, Fig. 9. This test piece is a small bottle provided with a ground glass stopper having a fine capillary opening through it. The bulk volume of the bottle and stopper is equal to that of the test piece for which the porosimeter is designed. (Cf. Sec. 67.) The bottle and stopper are accurately weighed, first empty and then filled with water at known temperature. Finally the bottle is filled with water, stoppered, and weighed suspended in water at known temperature. From these data the porosity, x_s, of this standard test piece can be accurately computed. Its porosity can also be varied between x_s and 0, by placing in it known weights of mercury. It is thus evident that by using such standard test pieces the porosimeter can be checked at any point on the porosity scale and a curve of corrections prepared, based either upon the procedure given in Sec. 63, or upon that procedure with the omission of the readings R'_m and R. From this curve the correction which must be applied to any measured porosity in order to obtain the correct value, can be read off directly.

From time to time it will be necessary to remove the mercury from the porosimeter so that both the mercury and the porosimeter may be cleaned. When the porosimeter is refilled, care should be taken to use always the same quantity of mercury, or rather that quantity of mercury which gives the same reading on the burette scale when the mercury in the bulb stands at mark C.

If the flexible connecting tube stretches appreciably under the varying mercury heights employed, the calibration correction will vary somewhat with the bulk volume of the test piece as well as with its porosity. With a properly constructed flexible tube this latter variation will, however, be entirely negligible. In any case its magnitude could obviously be determined, if desired. It is, of course, desirable to check a few points on the calibration curve occasionally.

66. Precision Discussion.—The precision attainable in the result depends upon the volume of the porosity bulb, upon the bulk volume and porosity of the test piece and upon the diameter of the burette and is calculable for any given case.

As an illustration of the precision attainable, a calculation will be made for the particular apparatus employed in the experiments described below. This apparatus was not designed to give the maximum attainable accuracy, but was designed to employ rectangular test pieces and to give all the accuracy required for ceramic bodies, other than highly vitrified porcelains.

The burette had a cross-section of one square centimeter. The green test pieces were rectangular briquettes 4 in. long and 1 in. square. The porosity bulb was approximately 100 cc. in volume.

In computing the precision attainable in x (equation 20) we will assume that each of the quantities, V, B, $R'_c - R'_m$, and $R - R_\circ$ can be measured with a precision of ±0.5 mm. on the scale of the burette, a precision which is attainable with careful work.

By differentiating equation (20) separately with respect to each of these quantities and substituting the numerical values indicated, we obtain the following expressions for the separate effects:

For $V(=100 \text{ cc.})$, $\Delta_1 = 0.05$ cc. and

$$\Delta x_1 = \frac{-x\Delta_1}{V-(R-R_\circ)} = 0.001x \qquad (21)$$

For $B(=750 \text{ mm.})$, $\Delta_2 = 0.5$ mm. and

$$\Delta x_2 = \frac{x\{[V-(R-R_\circ)]+100(R-R_\circ)\}}{B(R-R_\circ)} = \frac{(100+x)}{750} \qquad (22)$$

For $R'_c - R'_m$, $\Delta_3 = 0.5$ mm. and

$$\Delta x_3 = \frac{x\{[V-(R-R_\circ)]+100(R-R_\circ)\}^2}{100B(R-R_\circ)[V-(R-R_\circ)]} = \frac{(100+x)^2}{150{,}000} \qquad (23)$$

For $R - R_\circ$ $(=50 \text{ cc.})$, $\Delta_4 = 0.05$ cc. and

$$\Delta x_4 = \frac{Vx\Delta_4}{(R-R_\circ)[V-(R-R_\circ)]} = \frac{x}{500} \qquad (24)$$

The total error in x arising from the combined effects of all four errors will on the average be equal to the square root of the sum of the squares of the separate errors. In Table VIII are shown the magnitudes of the separate errors and the total error for bodies of different porosities.

TABLE VIII

ILLUSTRATING THE ABSOLUTE ERROR IN THE COMPUTED PER CENT POROSITY, x, PRODUCED BY THE SEPARATE AND COMBINED ERRORS IN THE FOUR VARIABLES MEASURED

Per cent porosity, x	Separate effects due to the error in				Average total error
	V (=100 cc.)	B (=750 mm.)	$R'_c - R'_m$	$R - R_o$ (=50 cc.)	
0.1	0.0001	0.065	0.067	0.0002	0.09
.5	.001	.065	.068	.001	.09
1.0	.001	.067	.068	.002	.09
5.0	.005	.070	.074	.01	.10
10.0	.01	.073	.081	.02	.11
20.0	.02	.080	.096	.04	.13
50.0	.05	.10	.15	.10	.21
60.0	.06	.11	.17	.12	.24
80.0	.08	.12	.22	.16	.31
90.0	.09	.13	.24	.18	.34
100.0	.10	.14	.27	.20	.38

67. Principles of Design.—The precision attainable with the porosimeter may be controlled to a considerable degree by establishing the proper relation between the bulk volume of the test piece and the volume of the porosity bulb so as to produce the most favorable value for the free volume, V_F. If the bulk volumes of the test pieces are more or less fixed by other conditions, then for the highest precision a set of several porosity bulbs of different volumes should be available. With a given porosity bulb, however, the maximum precision can be secured by using a test piece of the proper bulk volume in each instance. This bulk volume is a function of the porosity to be measured and is obtained by subtracting from the volume of the porosity bulb, the most favorable value for the free volume, V_F, that is, the most favorable value for $R_o - R$ in equation (20). The most favorable value for $R_o - R$ may be computed from the equation

$$\Delta x = \sqrt{\Delta x_1^2 + \Delta x_2^2 + \Delta x_3^2 + \Delta x_4^2} \qquad (25)$$

where the quantities under the radical are those expressed by equations 21 to 24 inclusive, the most favorable value for $R_o - R$ being that value which makes the right hand member of equation (25) an arithmetic minimum. For practical purposes it will not be necessary to meet this condition very closely except when working with bodies either of very high or very low porosity. In connection with the latter class of bodies some further discussion of this matter will be given in the next paper of this series.

68. The Rapid Porosimeter. Research Type.—It is obvious that minor details in the form and method of assembling the various parts of the rapid porosimeter are possible without changing the main principles of operation. The style described in the preceding pages was selected as probably the most desirable one for ceramic routine testing purposes in laboratory or plant. It is comparatively inexpensive to construct and to repair if accidently broken, easy to operate, and entirely satisfactory from the standpoint of accuracy. Indeed the errors in measurement will always be smaller than the variation in the porosity of different test pieces from the same lot, except possibly in the case of highly vitrified porcelains.

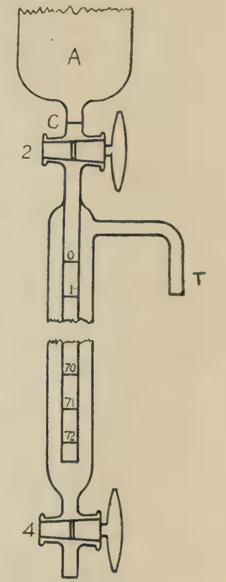

Fig. 11.—Rapid porosimeter, research type.

For research purposes, however, especially with non-ceramic materials, where still greater accuracy as well as absolute permanence of calibration are desired, an all-glass apparatus with no moving parts offers certain advantages. Such an apparatus is shown in Fig. 11. It is essentially the same apparatus as that shown in Fig. 8 but with the stem, S, of the porosity bulb lengthened and permanently sealed into the burette tube, B, and with the graduations (centimeters and millimeters) placed upon the stem, S, instead of upon the burette tube itself. *Such an amount of mercury is placed in the apparatus as to cause the meniscus in the burette tube to stand exactly at zero when the meniscus in the stem stands exactly at mark C.*

The apparatus is operated as follows: With the test piece in place and stop-cocks 1 and 2 open, apply air pressure at T until the porosity bulb is filled. Close stop-cock 2 and release the air pressure so as to leave T open to the atmosphere. Open stop-cock 2 until the mercury stands in the center of the bore of stop-cock 1. Then read the burette. This reading determines the free volume, V_F, and hence also the bulk volume, V_B, of the test piece in burette scale units.[42]

The pressure reading is now determined as follows: Close stop-cock 1, open 2 and with the aid of 4 draw off mercury until the meniscus stands a little above mark C. When equilibrium is reached adjust until the meniscus stands exactly at mark C and read the position of the mercury surface in the burette tube.

The porosity can now be calculated from these two readings, the constants of the apparatus, and the effective barometric pressure. The effective barometric pressure is determined in the same way as the pressure reading just described, but with the reference piece substituted in place of the test piece. All mercury drawn off through stop-cock 4 must be carefully returned to the apparatus after removing the test piece. This is also true of any mercury accidentally removed with a test piece. The amount of mercury in the apparatus must be kept constant or else an additional reading will be required each time. The whole apparatus can be calibrated in the manner described in Sec. 65, and such calibration will be permanent.

The precision of the volume readings depends upon the relative diameters of the stem and the burette tube and can obviously be made as great as desired.

The advantages of this style of apparatus over that of Fig. 8 are obvious. It is, however, more expensive to construct and requires a supply of compressed air for its operation, although the latter might be replaced by a leveling bulb attached below stop-cock 4, if desired.

69. Experimental Results.—In order to compare the results obtained by the gas expansion method with those given by the method of liquid absorption, fifteen test pieces of various porosities were studied. The porosity of each piece was first measured in the porosimeter, using in successive experiments; (1) air from the room, (2) dry hydrogen and (3) dry helium, respectively, as the pore filling gas. In introducing the last two gases the porosimeter containing the test piece was first evacuated to a high vacuum and the pure gas then admitted until atmospheric pressure was attained.

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[42] If these volumes are desired in cubic centimeters, it is only necessary to multiply by the appropriate factor for converting burette scale units into cc. This is not necessary, however, if the porosity only is required.

After completing the measurements in the porosimeter, test piece No. 6 was boiled for 5 hours in distilled water at atmospheric pressure and weighed. Test pieces 4, 6, 10, 11 and 12 were then saturated with water at room temperature by the vacuum procedure of Section 47 above. After weighing, these test pieces were then dried in vacuo at 100°, followed by a short calcination at red heat. All 15 pieces were then saturated with vaseline at 200° using the procedure of Section 47. The results obtained together with the soaking times employed are shown in Table IX.

TABLE IX

COMPARATIVE RESULTS OBTAINED BY THE "GAS-EXPANSION" AND THE "LIQUID-ABSORPTION" METHODS OF DETERMINING THE POROSITY OF CLAY WARE. FIRST NINE BODIES FIRED TO CONE 10, NEXT THREE TO CONE 03 AND LAST THREE DRIED AT 120°C BUT NOT FIRED

Test piece no.	Body	Per cent porosity with pore filling fluid					
		Air	H_2 or He	Water	Hours soaking	Vaseline	Hours soaking
1	Stoneware	13.9	13.9	...	..	11.9	3
2	Stoneware	19.2	19.2	...	..	18.2	3
3	Stoneware	36.4	36.4	...	..	34.6	2
4	Stoneware	12.2	12.2	9.3	90	1.2 8.4	24 120
5	Stoneware	23.8	23.8	...	..	21.5	18
6	Stoneware	15.6	15.6	14.8[1]	24	2.3 13.5	2 120
7	Stoneware	15.4	15.4	...	..	12.4	18
8	Stoneware	15.8	15.8	...	..	10.7	18
9	Fire Clay	26.4	26.4	...	..	24.2	18
10	Red Clay	35.3	35.3	32.0	24	32.0	24
11	Red Clay	37.1	37.1	31.7	24	32.0	24
12	Red Clay	34.4	34.4	31.0	24	31.0	24
13	Stoneware	32.4	30.2	...	..	27.2	45
14	Red Clay	36.2	34.2	...	..	27.0	45
15	Red Clay	36.2	34.2	...	..	26.8	45

70. Discussion of Results.—Helium is known to be not adsorbed appreciably at room temperature. The identity of the results obtained with the fired bodies in the case of all three gases shows, therefore, that no appreciable error from adsorption is to be feared in using air in the porosimeter for porosity measurements with this class of bodies. With the unfired bodies, however, the results obtained with air indicate that small but appreciable quantities of air are adsorbed. Some of this air is given off in the porosimeter thus causing too high results. With hydrogen and helium on the other hand identical results were obtained, thus showing that hydrogen may be safely employed as the pore filling gas when results of high accuracy are desired with unfired bodies. For most practical purposes, however, an accuracy of one unit in the per cent porosity of unfired bodies is ample and this could probably be secured by applying a definite percentage correction to the results obtained with air, the magnitude of this correction being obtained by means of a sufficiently extensive study of various types of unfired bodies using both air and hydrogen as pore filling agents.

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[1] Test piece No. 6 on boiling in water for 5 hours at atmospheric pressure and weighing gave a porosity result of only 3 per cent.

The results obtained with the absorption liquids are, in all cases, appreciably lower than those obtained with the gases and the importance of a long soaking period is evident, thus showing, especially in certain cases, the presence of a considerable volume of micropores which are filled with extreme slowness by the liquids. In the case of test piece No. 4 the presence of these very fine pores was apparent even when using the porosimeter since it required nearly 30 minutes for the gas to issue from all of these pores and equalize the pressure. In other words, a constant value for R'_m was not reached until half an hour had elapsed. With test pieces Nos. 1, 2, 3, 5, 9 and 10 there is fair agreement between the results of the gas expansion method and those of the liquid absorption method (although the former are in all cases higher) and this agreement could be bettered by employing longer soaking times or higher pressures. These bodies evidently do not contain any considerable volume of micropores and with such bodies the liquid absorption method will be reasonably reliable, although the soaking time should be greatly increased over what has been the practice in the past or high pressures should be employed.

71. Bodies with Large Pores.—For determining the porosity of bodies, such as "Non-pareil" brick, having very large pores, the porosimeter is not suitable since all such pores on the surface of the test piece would be filled by the mercury. By filling the surface pores with paraffine, however, the bulk volume of the test piece could be accurately determined and such a determination combined with the data secured from a previous measurement of the total pore volume by means of the *General Method* (Sec. 55) would give an accurate value for the porosity. In other words the gas expansion principle, as employed in the *General Method*, is applicable to any body for which the bulk volume can be determined by any suitable procedure.

72. Bodies of Very Low Porosity.—The use of the gas expansion method for highly vitrified bodies will be discussed in the next paper of the series where the results of some studies of electrical porcelain will be presented.

XIX. Conclusions

73. Advantages of the Gas Expansion Method.—(1) It will give correct results even in the case of bodies containing a very considerable volume of micropores or of pocket pores (Cf. Sec. 3) with narrow openings. (2) It is not necessary to dry or to weigh the test pieces at any stage of the process. (3) In its general form the method is applicable to bodies of any size or shape (including granular material) provided the bulk volume or bulk density of the body or material is known or can be determined. (4) Since the method employs no pore filling liquid it does not injure or alter the test piece or material in any way. (5) In its rapid form the method is sufficiently rapid for all practical purposes. If a number of test pieces are to be measured, the average time consumed in a complete determination of the porosity is, per test piece (*a*) 2 to 3 minutes for an accuracy of one unit in the result or (*b*) 5 to 10 minutes for an accuracy of 0.1–0.3 unit in the result. (6) The method seems to be entirely suitable both as a practical engineering method and as a *standard reference method* for *all* classes of bodies.

74. Acknowledgment.—We desire to express our appreciation of the kindness of Dr. R. B. Moore of the U. S. Bureau of Mines in supplying us with a cylinder of pure helium for use in the experiments recorded in Sec. 69.

(*To be continued*)

JOURNAL AMERICAN CERAMIC SOCIETY

Preparation of Abstracts

Every article in THIS JOURNAL is to be preceded by an abstract prepared by the author and submitted by him with the manuscript. The abstract is intended to serve as an aid to the reader by furnishing an index and brief summary or preliminary survey of the contents of the article; it should be suitable for reprinting in an abstract journal so as to make a reabstracting of the article unnecessary. The abstract should, therefore, **summarize all new information completely and precisely.** Furthermore, in order to enable a reader to tell at a glance what the article is about and to enable an efficient index of its subject matter to be readily prepared, the abstract should contain **a set of subtitles** which together form a **complete and precise** index of the information contained in the article. This requires at least one and often several subtitles even for a short abstract.

In the preparation of abstracts, authors should be guided by the following rules, which are illustrated by the abstracts in THIS JOURNAL for February and March, 1921.* The **new information** contained in an article should first be determined by a careful analysis; then the subtitles should be formulated; and finally the text should be written and checked.

Rules

1. **Material not new** need not be analyzed or described in detail; a valuable summary of a previous work, however, should be noted with a statement indicating its nature and scope.

2. **The subtitles should together include all the new information;** that is every measurement, observation, method, improvement, suggestion and theory which is presented by the author as new and of value in itself.

3. **Each subtitle should describe the corresponding information so precisely** that the chance of any investigator being misled into thinking the article contains the particular information he desires when it does not, or vice-versa, may be small Such a title as "A note on blue glass," for example, is evidently too indefinite a description of information regarding "Absorption spectra of glass containing various amounts of copper-cobalt and chromium-cobalt." General subtitles, such as "Purpose" and ' Results" should not be employed as they do not help to describe the specific information given in the article.

4. **The text should summarize the authors' conclusions and should transcribe numerical results of general interest,** including those that might be looked for in a table of physical and chemical constants, with an indication of the accuracy of each. It should give all the information that anyone, not a specialist in the particular field involved, might care to have in his note book.

5. **The text should be divided into as many paragraphs** as there are distinct subjects concerning which information is given, but no more than necessary. All parts of subtitles may be scattered through the text but the subject of each paragraph, however short, must be indicated at the beginning.

6. **Complete sentences** should be used except in the case of subtitles. The abstract should be made as readable as the necessary brevity will permit.

7. The ms. of all abstracts must be typewritten and double or triple spaced.

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* The rules were prepared by the Research Information Service of the National Research Council. The Society is indebted to Dr. G. S. Fulcher of the Corning Glass Works (formerly with the National Research Council) for the rules and the illustrative abstracts.

JOURNAL

OF THE

AMERICAN CERAMIC SOCIETY

A monthly Journal devoted to the arts and sciences related to the silicate industries.

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Vol. 5 **March, 1922** **No. 3**

EDITORIALS

THE SECOND CONFERENCE OF THE INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

The second conference of the International Union of Pure and Applied Chemistry was held in Brussels on June 27–30, 1921, and a copy of the proceedings of this meeting has just been received. It will be recalled that the American Ceramic Society through its membership in the Division of Chemistry and Chemical Technology of the National Research Council was a party to the creation of the International Union and was represented by a delegate at the meeting in London in 1919, at which the Union was organized. The American delegates are chosen by the Division of Chemistry and Chemical Technology of the National Research Council but each of the constituent societies has the privilege of nominating delegates and alternates. This privilege has not been utilized by our Society since the London meeting and in view of the approaching third conference of the Union which is called to meet in Lyons, France, in June, 1922, some action should be taken to make possible the representation of the Society at this conference especially as some matters of ceramic interest are to come up for consideration.

The principal matter of special interest to the Society is a proposal made in a report presented to the Brussels meeting of the Union in the name of the national Belgian committee. A free translation of this report is presented below.

The point especially emphasized in this report is a vital one. Satisfactory and scientifically reliable methods for the testing of materials can not be developed merely from the discussions of committees and the survey of results of experience. Every problem of this character should receive a critical study in a laboratory properly equipped and staffed for such work. The final selection of a testing method to be adopted as a standard is a matter to be mutually agreed upon by competent engineers and chemists representing the industrial interests involved but the critical examination of proposed methods, the study of their errors and limitations and the development of improvements in accuracy, convenience and rapidity, is a problem for the trained chemist and physicist working in a properly equipped laboratory and with all the advice and assistance which the technical men in the industries are able to furnish.

With regard to a practical plan for international coöperation in this field the proposal of the Belgian committee raises several important questions. It is not probable that nations which themselves possess laboratories established for work of this character would care to make any considerable financial contribution toward the establishment and maintenance of an international testing laboratory but nations which do not have such facilities might well coöperate in this way. One of the prime functions of our own Bureau of Standards is the study of problems of this character and we could doubtless contribute most effectively to an international program in this field by coöperative arrangements between the Bureau of Standards and other similar laboratories now in existence or which may in the future be established in the other countries of the world. Such international coöperation in connection with electrical standards has been in existence for a number of years.

With regard to the specific recommendations of Messieurs Lecrenier and Huybrechts only one other adverse criticism seems to us to be called for and that is with respect to the directive machinery which they propose for such a laboratory. Their plan provides for a representative committee of chemists who would direct the work of the laboratory. Such a method of control seems to us inadvisable. An advisory committee of chemists and engineers representing all the interests involved is both necessary and desirable but the directive authority should be vested in the man chosen as the director of the laboratory, and while it is to be expected that he will work in close harmony and constant contact with his advisory committee he should have a large measure of authority in determining the policies and methods of work of the laboratory.

In acting upon this report the Union provided for the nomination of a permanent committee with at least three members from each country to be designated by the National Research Council (or its equivalent). In each instance, of the three members thus chosen, one is to be an expert on solid fuels, one on liquid and gaseous fuels and the third on ceramics. The American members of this committee have not yet been selected and the Society should study the questions involved and be prepared to make suggestions concerning American representation and concerning all the questions involved in the proposal.

The Establishment of National and International Laboratories for Ceramic and Fuel Investigations

A REPORT PRESENTED TO THE SECOND CONFERENCE OF THE INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY IN THE NAME OF THE NATIONAL BELGIAN COMMITTEE

Chemists seem to be in accord with respect to the inestimable advantages of approved methods for the analysis of minerals and industrial products. In a report presented to the First International Chemical Conference held in Rome in 1921, M. Nicolardot summarized the results which have thus far been obtained in this direction. He demonstrated that the labors of commissions which have at various times been created with this end in view have yielded no practical results. He attributes this failure to lack of financial resources, to the absence of a central laboratory, and to the lack of authority on the part of the commissions to compel the adoption of their recommendations.

We should, however, not lose sight of the great scientific value of experimental results which have been brought together, compared and discussed and the conclusions which have thus been reached. Unfortunately these are known to but few chemists and the pains which certain of them have taken to make these results and conclusions more generally known have had no appreciable success.

Such work ought to be very productive and in our opinion it should be continued under a different type of organization, free from the defects of past attempts. The new organization should provide especially for the establishment of national and international laboratories supported by subsidies from the State and the industries and these laboratories should be directed by a representative committee of chemists.

In order to insure a maximum output such a laboratory should, at least at the start, concentrate its efforts upon a comparatively small number of projects. We believe that, because of their great industrial importance, the first problems to be attacked should be those relating to fuels and to ceramic raw materials and products, especially refractory materials. The study should cover products including a wide range of compositions and the various testing methods should be compared from the point of view of accuracy and rapidity.

One of the first consequences of such a study of testing methods would be the disappearance, in a large measure, of existing disagreements and it would also carry with it a consequent economy for the industries, since the latter would then be in a position to carry out in their own laboratories many routine tests for which at present they are dependent upon outside laboratories.

If one wished to sketch briefly the procedure for such an investigation one would include the sampling, the preparation of the test piece, and the analysis proper. The procedures elaborated should be described in detail and the reason for each step explained and scientifically justified. The results obtained by different procedures should be compared and should, of course, be stated in uniform terms. The additional tests, of a physico-chemical character, such as mechanical analysis, pyrometric tests, the resistance of refractories to attack by gases and fluxes, etc., should be carried out for the purpose of ascertaining the relation between the physical properties of such materials and their chemical and mineralogical composition. The program which we have sketched above is not intended to restrict the field of investigation but merely to emphasize some of the more important problems.

In the case of fuels it would be advisable, in our opinion, to cover methods of sampling, preparation of the sample for analysis, the chemical analysis proper, the determination of the calorific power, the determination of such physical properties as density, viscosity, ignition point, etc. (in the case of liquid fuels), methods of using the fuel, its coking behavior, the agglutinating power of oils, the conservation of coal, the testing of illuminating gas, the manufacture of coke, its by-products, briquetting, pulverized fuels, and finally the combustion apparatus.

After these systematic investigations on refractories and fuels, other problems should be taken up in accordance with a well-thought-out program. The results of the work should be published and widely distributed so that they may be read by everyone interested. The methods of analysis and testing would not be compulsory upon chemists but we are convinced that such procedures, established with scientific disinterestedness and as a result of the collaboration of all competent chemists, would acquire such a prestige as to insure their general adoption. They would, of course, always be subject to future modifications and would be regarded not as a final solution of the analytical problems but as a point of departure for future progress.

(*Signed*) A. LECRENIER
M. HUYBRECHTS

ABSTRACTS FROM THE JOURNAL OF THE JAPANESE CERAMIC SOCIETY

The members of the Society will be glad to learn that through an arrangement with Professor Seiji Kondo, Director of the Ceramic Department of the Tokio Higher Technical School, Asakusa, Tokio, Japan, all papers published in the Journal of the Japanese Ceramic Society will be regularly abstracted in English and the abstracts will be published in *Ceramic Abstracts*.

ORIGINAL PAPERS AND DISCUSSIONS

A DEVICE FOR TESTING THE RESISTANCE OF CHINA TO CHIPPING[1]

By Edward Schramm

ABSTRACT

The device (shown in the figure) measures the blow required to chip the edge. Results are reproducible to within about 10%, this variation being due to lack of uniformity in the pieces tested. Vitrified china is more resistant to chipping than is semi-porcelain or European true porcelain.

In a paper[2] by H. F. Staley and J. S. Hromatko the modes of failure of tableware in service are discussed at length and a pendulum impact test designed to approximate service conditions is described. The work was confined to heavy hotel china plates of various makes. It was found that the design of the plates was an important factor in their resistance to impact. All the data given refer to the true impact test, *i. e.*, to the determination of the energy of the blow required to produce total failure; however, in the summary it is pointed out that one characteristic difference between vitrified and semi-porcelain ware lies in the greater resistance of the former to chipping under light blows. No attempt was made to estimate resistance to chipping quantitatively. Now for certain classes of service, notably thin dinner ware, this property is at least equal in importance to the ability to withstand heavy blows without fracture.

Accordingly an apparatus of the pendulum type was constructed especially adapted to chipping tests. The photograph will make the principle clear. The stand is built of $2^1/_2$-inch seasoned oak. It consists of a base piece with a short upright at one end carrying

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[1] Received January 18, 1922.

[2] *This Jour.*, **2**, 227 (1919).

a shelf on a pair of heavy hinges. The shelf can be adjusted to any desired angle by turning the supporting screw which works into a thread in the base. By this means the leaf of the plate can readily be brought into a horizontal position regardless of its angle. The backing for the plate is provided by a block, cut into a V on one side and faced with hardened steel plates. The block is clamped to the shelf by means of a threaded bolt which travels in a slot in the shelf; this block is guided by two small dogs sliding on the sides of the shelf in such a manner that the point of the V moves in the plane of the pendulum. The block is clamped in the position appropriate for the particular size of plate being tested. It provides a backing for the plate and also serves to center the latter so that the pendulum always strikes at 90°. The pendulum is rigid and is supported by a bronze collar rotating on a steel shaft which is clamped to a heavy post. The post also carries the arc of 1 foot radius graduated in degrees. The pendulum collar is made $2^1/_2$ inches long to give a true guide, but is hol-

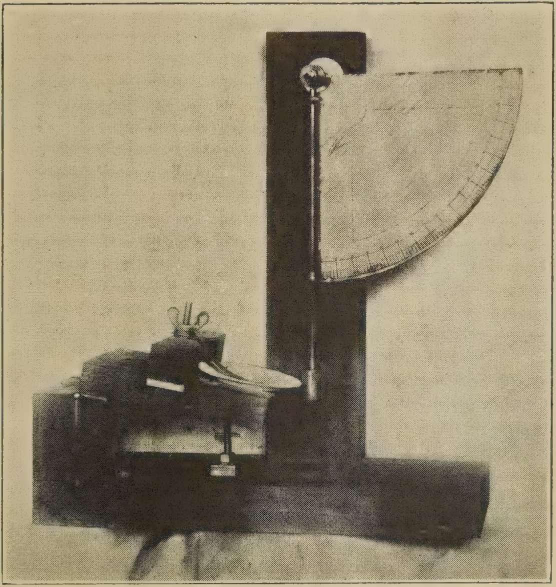

Fig. 1.

lowed out in the center to reduce the bearing surface. A brass rod four inches long screws into the middle of the collar and over this slides a $^3/_8$-inch brass tube split at the top and provided with a clamping nut to allow adjustment in length. The bob (which may be changed to suit conditions) is a piece of $1^1/_4$-inch steel rod, case hardened and threaded to fit the brass tube. The position of the pendulum is read by means of a small indicator attached to the tube.

In use the plate to be tested is placed on the shelf, being held in place by a steel spring, and the shelf raised or lowered to bring the top of the leaf horizontal. The backing block is adjusted to bring the edge of the plate in contact with the bob in its zero position, and α, the angle of swing at which the first chipping occurs, is noted. Trials are made at ten points around the circumference of the plate and the average value taken. From the angle α the corresponding energy of the blow can be readily computed; or if the length and mass of the pendulum are fixed we may take as the resistance to chipping, 1-cos α.

Judging from experience to date we may state that the chief difficulty in the way of securing consistent results lies in lack of uniformity of the pieces tested rather than in the apparatus or method. Variations in shape and thickness have a marked effect, and if these can not be controlled we must depend on the averages of a large mass of data. This holds true in almost equal degree for the true impact test employed by Staley and Hromatko. The latter expressed their results in terms of the energy per unit thickness on the assumption that strength is directly proportional to thickness but there is no evidence in support of this assumption. Before comparisons can be made of pieces of different weights or shapes the effect of these variations will have to be worked out. In studying the comparative behavior of different bodies we used the expedient of numbering the moulds and making plates of the several bodies on the same mould and under otherwise identical conditions.

Some typical results are given in the following table showing in each instance the mean of ten measurements, the average and the maximum deviations from the mean and the corresponding value for 1-cos α.

TABLE I

Body	Mean α (degrees of arc)	Av. dev.	Max. dev.	1-cos α
Body A, Mould N. Edge of leaf 0.09 inch	15.0	2.3	6.0	0.034_2
Body B, Mould N	21.0	1.6	3.0	0.066_4
Body A, Mould P	18.2	3.4	6.0	0.050_0
Body B, Mould P	21.3	2.9	6.0	0.068_3
French porcelain, same thickness as above	11.1	0.9	4.0	0.0187_1
English bone china 25% thicker than above	16.1	1.6	4.0	0.039_2

From our work to date the indications are that in resistance to chipping vitrified china is not only superior to semi-porcelain as shown by Staley and Hromatko, but is also better than the European type of true porcelain.

It will be obvious that the apparatus as described will serve equally well for true impact tests if a ball is substituted for the cylindrical bob and an auxiliary vertical plate support is provided.

ONONDAGA POTTERY CO.,
SYRACUSE, NEW YORK

THE DEVELOPMENT OF CERAMIC WORK AT THE UNIVERSITY OF NORTH DAKOTA[1]

By Margaret Kelly Cable

ABSTRACT

The development of the Ceramics Department of the University of North Dakota; correlation of research in chemical and experimental laboratories and cultural value of the work; inexhaustible supplies of the state being utilized.

The ceramic work at the University of North Dakota had its conception in the research work of the School of Mines on the high grade clays of the State.

There are many different types of clays in North Dakota undeveloped, yet suited to the manufacture of a great variety of ceramic products from common brick to those higher grades of pottery which are the most exacting in their chemical and physical requirements.

As North Dakota is relatively a young State there has not been time to thoroughly investigate and develop many of its resources. This is particularly true of its great deposits of lignite and its varied and valuable clays, some of the finest of which are found in close proximity to extensive deposits of lignite capable of supplying abundant and cheap fuel, so important in the development and economies of a ceramic industry.

The preliminary investigations of the School of Mines made so evident the high quality of many of these clays that it seemed desirable to provide facilities for their more detailed technical and practical study. As a result the Ceramic Department of the School of Mines was established.

Although its primary purpose was to afford better research facilities in ceramics, it soon became evident that this, both for technical and economic reasons could be coupled advantageously with instructional work, utilizing thereby the equipment, the technical

[1] Received December 26, 1921.

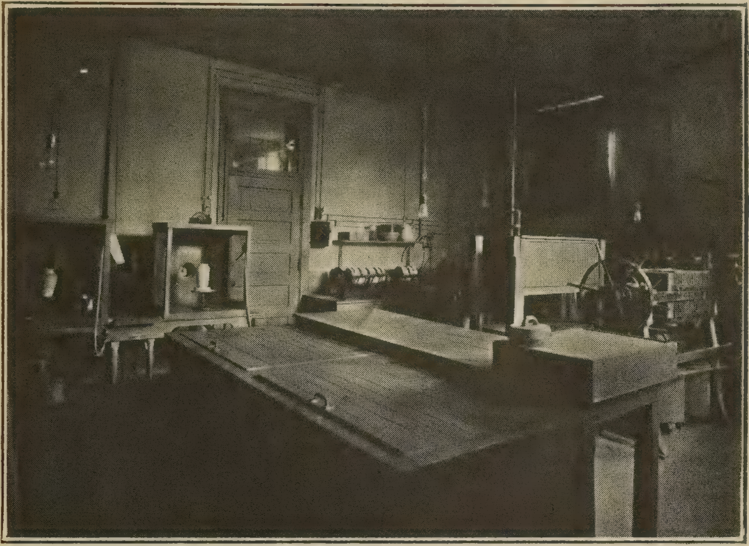

FIG. 1.—Slip room, Ceramic Department, School of Mines, University of North Dakota.

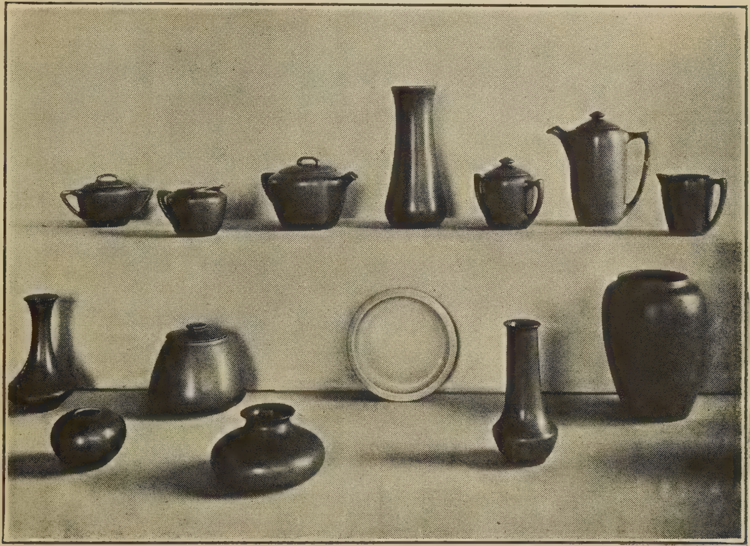

FIG. 2.—Art pottery made at the School of Mines, University of North Dakota.

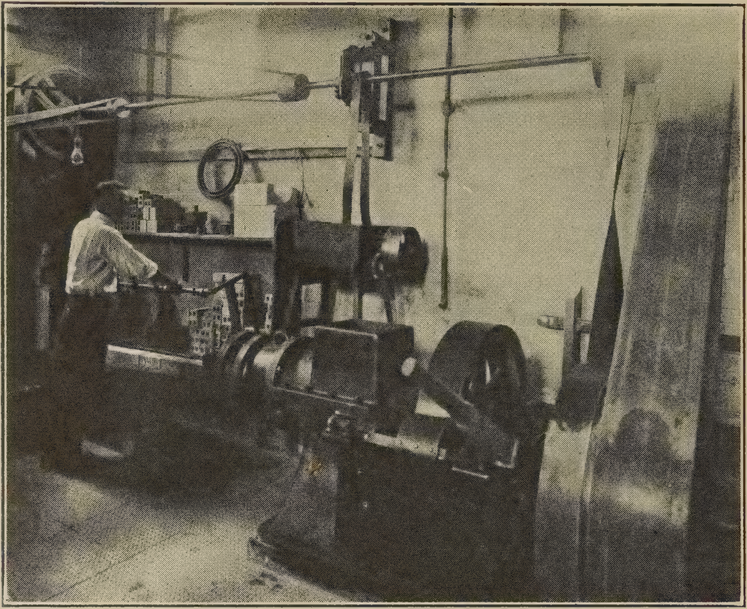

FIG. 3.—Brick machinery, Ceramic Department, School of Mines, University of North Dakota.

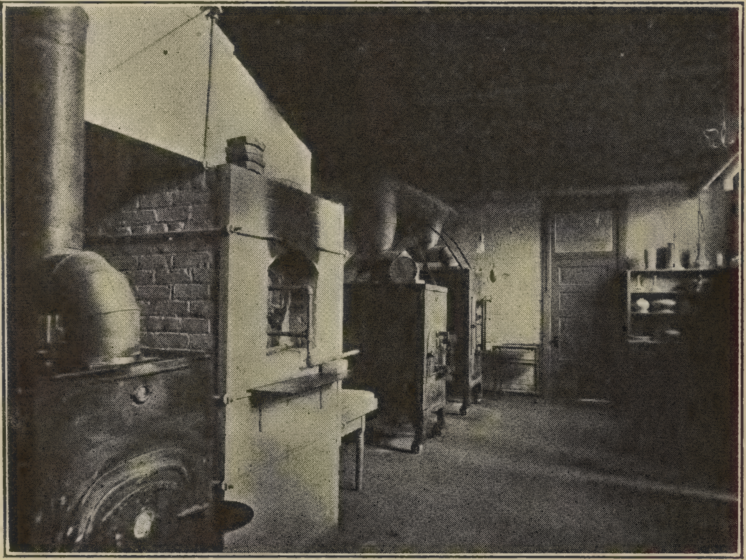

FIG. 4.—Kiln room, Ceramic Department, School of Mines, University of North Dakota.

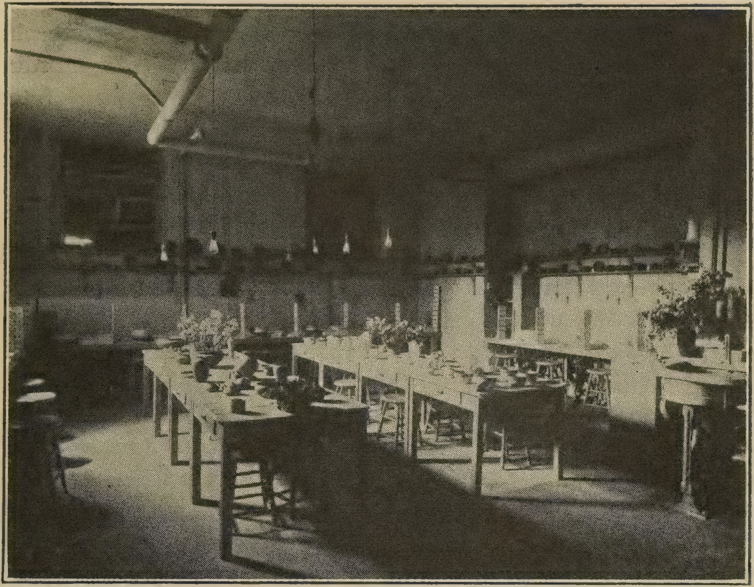

FIG. 5.—Pottery laboratory, Ceramic Department, School of Mines, University of North Dakota.

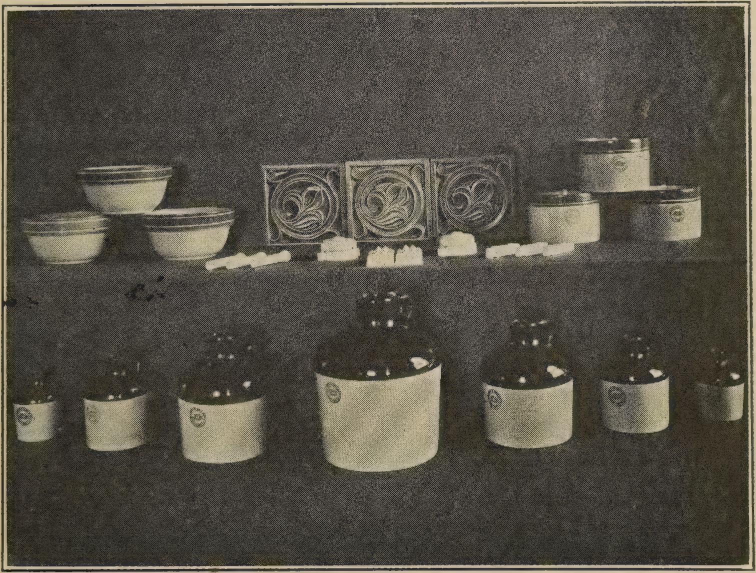

FIG. 6.—Stoneware, tile, etc., made at the School of Mines, University of North Dakota.

force and later, the contributions of advanced students in securing a larger volume of research work, while at the same time affording an opportunity for instruction and training to young people interested in the great field of ceramic technology.

From time to time the courses of instruction originally outlined have been extended and other courses added although they have not as yet been developed into a curriculum leading to a ceramic degree. On the other hand students in mining and industrial engineering are given an opportunity to take some of these technical courses as ceramic electives. Other courses are open as electives to students in the College of Liberal Arts and in Teachers' College.

As the pottery industry is one of the best illustrations of the combination of industry, science and art, its study is therefore very worthy of a place in a university curriculum. For this reason we have emphasized somewhat the pottery phase of the industry and have aimed to keep constantly before the students its scientific and cultural value as well as its practical value. We have also felt that if we could prove, in our research work with our higher grade clays, their fitness for the more exacting and more beautiful types of products we could, with comparative ease, work downward in our research into those types of clays fitted for the more common products. This plan has proved very successful. Our students have taken a deep interest in the work because they are dealing with actual problems concerning our undeveloped resources, and because they are lead to see the direct application of science to this study and the really artistic and beautiful products which may be created by the application of technical methods combined with careful design and manipulation.

The result has been a much larger demand for the work than we have been able to accommodate. We have reached an enrollment in these various courses of over sixty, with a waiting list of nearly as many more.

We have endeavored to put our work on a scientific, technical and practical basis from the start using the methods of investigation and operation which would be employed in the most up-to-date industrial plants. Our chemical and experimental laboratories have, therefore, been well equipped for clay testing, and the clay-working laboratories have been provided with standard types of machinery for actual production by the same methods as employed in the various lines of ceramic industries. We have endeavored to make our clay-working laboratories what might be called small working plants and in so doing we have developed on the one side a small brick and tile unit for the practical working of clays adapted to construction material and on the other side a pottery unit. In this way all of the essential operations can be carried on in either line of work by standard methods and by standard equipment.

The character of the work has steadily improved until the products, especially in our classes in practical pottery, are of excellent quality and of such a character as to prove beyond a doubt that there are many deposits of exceptional clays in North Dakota well fitted for the production of high grade stoneware, earthenware, art pottery, etc. In addition to our instructional work we are accumulating a large amount of technical and practical data on our undeveloped clays.

When we consider the quality and the proximity of some of these deposits to inexhaustible supplies of fuel there seems to be no reason why in the near future North Dakota should not be ranked among the important states in the ceramic industry.

University of North Dakota
Grand Forks, N. Dak.

THE HANDLING, STORING AND SETTING OF GLASS POTS[1]

By Wm. M. Clark and J. H. Forsyth

ABSTRACT

"A glass pot is a wonderful piece of engineering:" It is an expensive article and deserves the most careful treatment. The precautions indicated are; careful packing for shipment in *rain proof* box cars, well padded pot carriages equipped with the spring suspensions, storage in a *warm, dry* room, careful preparation of furnace bench to insure an *even distribution of load* on the bottom of the pot and to make certain that the pot is *level,* or tilted slightly forward. Unnecessary jolts often result in damage which only becomes apparent when the pot is heated up.

Introduction—Preliminary Precautions

The point that should always be held uppermost in mind concerning a glass melting pot is that it is really a marvelous piece of engineering. A mass of clay weighing around one and one-half tons, moulded, shaped and carefully dried, which will stand the rough treatment necessitated in shipment is remarkable. This body of clay has been nursed and petted from the laying of the bottom to the state of final drying in the pot room and from its very nature is fragile, and its mechanical strength, weak.

The fact that the pot must be shipped by box car, is an unfortunate necessity but all possible means should be used to protect this mass of unburned clay both in the car and up to final setting in the furnace.

Shipment

The presumption is that a water tight box car has been selected for shipment and it may be well to have water from a hose flow over the roof of the car to fully demonstrate that it is rain proof.

The pots should be set on dry packing hay and well braced so that they can not shift position or be jarred during transit.

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[1] Received November 14, 1921.

Unloading and Storage

When the car is received in good order it is well to have a yoke or block and tackle arrangement to raise the bottom of the pots up to the level of the pot carriage. Carriages should be well padded with canvas strips or rubber hose, and it has been found advantageous to have spring suspensions and roller bearings to avoid jolts when crossing thresholds, rough flooring and other irregular surfaces. All straining, jolting and jarring should be eliminated whenever possible.

Possibly the careless maner in which pots are sometimes handled is due to the fact that the result of jars or strains is ofttimes not apparent while handling the pot but shows up at later stages, for instance during the heating-up period in the pot arch. In such cases cracks due to the release of strains set up in handling can be very easily accounted for by a number of different causes and the real origin remain a mystery.

Pots should be stored in a dry place selected for this sole purpose, such as beneath the furnace room. This space should be fenced off with wire netting and provided with a door and lock so that only the furnace man has access to the room. The bottoms should be raised on blocks to give opportunity for air to circulate beneath. Naturally the oldest pots should be used first and the storage room should be so arranged that they will be withdrawn in natural sequence.

A card record giving the life history of each pot from the time it is received until it is removed from the furnace is advisable so that the individual performance of each pot is known, its inferior or superior qualities may be traced and the results transferred to a summary sheet.

A typical card may be arranged as follows:

POT RECORD Glass Co. DATE
Furnace No.————Arch No.————
Pot Broken————Maker————No.————
Remarks————
How Broken, etc.
Size, etc.
Pot Set— — —Maker————No.————

Summary Pot Record————————Glass Co. Arch No.——

Maker's Name	Set	Broke	Life	Remarks	Melts.
and No. /	/	/ /	/	// / /	/ / /
					Total————

Etc.

The majority of plants have only hand drawn pot carriages. If the volume of business warrants, however, it is advisable to adopt power driven carriages, either electric trucks, or, for furnace room work, steam driven pot handling machines.

A successful departure from usual practice followed at one plant was to construct a pot room alongside of a checker chamber by merely enclosing the space for a few bays with a brick or tile wall. The waste radiated heat from the checker chamber kept this room warm and pots were transferred here from the storage room preliminary to introduction in the pot arch, so that they were evenly and well dried out and somewhat heated when ready for the pot arch.

Contrast this care with what is sometimes found around glass works: pots stored in cold warehouses, or any odd space in the plant, sometimes near broken windows where snow and rain beat in and other exposure to moisture is present.

A glass pot is a wonderful piece of engineering skill when we consider the great weight, thick walls, long time required to manufacture and severe treatment to which it is to be subjected. There is no other appliance or tool worth one hundred dollars around a glass house which is not given better care or more closely watched lest it be damaged, and yet the pots are the main-springs of the business. Considering the loss of production and the arduous labor resulting from the loss of pots, is there any reason why all precautions should not be taken to prolong the life of the pot? Consequently elimination of every cause of jolts, jars and rough handling is most desirable.

Pot Setting

The setting of pots is an operation carried out by a well trained crew in fifteen or twenty minutes where a skillful foreman is in charge and a proper subdivision of labor is maintained so that each man knows his specific duties. It is one of the most spectacular features in connection with glass house operation.

It is well to remove the regular sheet metal doors just before pot setting, and to hang on the hinges an old set of doors which have been warped and scaled by exposure to the high temperatures and which are used only at the time of pot setting. The jack bricks composing the breast wall are torn out and piled conveniently at one side of the arch. Lastly the breast wall bricks are loosened by leverage, a carriage is inserted under them and they are wheeled to one side of the opening. The sheet metal doors serve as shadow pans in retaining heat within the furnace and thus protect the operators. Chain screens or wire gauze screens may be used advantageously for heat protection, comfort, and retention of heat within the furnace.

When the breast wall is clear the old pot is attacked. If glass has leaked out through a crack and frozen the pot to the bench considerable exertion may be required to remove this glass with rakes, shovels and hoes. Finally a pry is applied beneath the mouth of the pot until it can be raised and the prongs of the pot carriage forced beneath the bottom. Then the long handle of the pot carriage serves as a lever and the wheels as a fulcrum and the pot is lifted and carted off to the dump.

Meanwhile the other men start cleaning the bench and removing all traces of any glass that has leaked out. When they have an even clay bottom a cushion of clean sand is thrown over the bench and it is ready to receive the new pot. This is brought from the pot arch on the pot carriage and placed in approximate position and then gently lowered into place and the pot carriage withdrawn.

Care must be exercised that the pot is level. This is usually accomplished by the foreman taking special pains when the bench is cleaned to see that sufficient sand is used so that when the pot has settled into place only a small amount, if any, additional filling will be necessary.

The arduous labor of raking, hoeing, and spreading of sand in the above operations is greatly lessened if the leverage principle is used to full extent. This may be done by having extra long handled tools and employing a "Lazy Bones" as the fulcrum point.

Carelessness in cleaning the bench will result in the bench gradually becoming so high that the pot will not enter the arch of the furnace while still on the carriage. This means that the pot must be unloaded in the arch opening and shoved on the bed of sand into the furnace. Bunting the pot just under the hood with the pot carriage is the usual method of accomplishing this end. Although the pot at this point has been burned and possesses considerable mechanical strength vibrations set up by such rough treatment ought certainly to be discouraged.

The method practiced by one old hand at setting pots is to have the bench thoroughly cleaned and enough sand placed at the back of the pot so that the pot can be settled down to the proper level. The front of the pot can be easily barred up and sand thrown under to raise it but it is next to impossible to do this at the back. When the pots are not completely worked out it is a good plan to tilt the pot slightly towards the mouth thus relieving the back, or the weakest part of the pot when in the furnace, of the added pressure of the glass.

After the pot is properly leveled the breast wall bricks are wheeled into position on the block carriage. The jack bricks are lifted by means of forked rods into their proper positions so that a neat fitting breast wall results and the few interstices between the blocks are mudded up with clay in order to make a gas tight closure around the pot. Accurate placing of these jack brick is easily accomplished by using a bar as fulcrum for the jack brick fork. The bar can be held by two men or a stand for the same purpose may be employed.

It will be seen that only the very greatest pains can be advocated in all handling of pots if the best service is desired. Plants pursuing such care may be exceptional, but records from such plants prove that the results attained will justify the precautions taken.

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SUGGESTED NEW METHODS IN THE PREPARATION OF DUST-PRESSED BODIES[1]

By H. Spurrier

ABSTRACT

Milling.—A continuous pebble mill of the self-feeding type is recommended. Segregation due to difference in density is not to be feared.

Drying.—Instead of drying completely, wetting down, tempering, aging and grinding the author recommends drying the press cake only down to a water content of 16%, followed immediately by disintegrating and pressing. The pressed ware produced by this shortened procedure is very satisfactory.

A Combined Disintegrator and Dryer.—The author suggests the application of a hot blast to the clay as it leaves the mill for the disintegrator thus drying and disintegrating it in one operation. This suggestion has not, however, been tried out.

It is frequently of mutual advantage for a worker to be brought suddenly into contact with new phases of industry, because during the necessary learning process old activities will be viewed from new angles, and hoary trade practices, which have the stability of the pyramids, will be investigated apart from the blinding glare of universal assent, that damning attitude of mind which gave rise to the "As it was in the beginning, is now, and ever shall be," spirit which so successfully shackles human progress.

The writer had the good fortune, about a year ago, to be the worker end of the couplet above alluded to. In the preparation of clay for dust-press operations it soon became evident that, in order to secure constancy of finished dimensions, it was necessary to control the moisture content of the dust as this was found to be the greatest factor in controlling shrinkage. It is, however, quite difficult to do this, under current procedure where finished sizes of large pieces must be controlled within narrow limits, in order to avoid rejections.

On reflection it became evident that there were other points in current practice that might advantageously be revised. For instance the drying of clay, always inimical to the best working

[1] Received January 30, 1922.

properties of plastic bodies might be so controlled as to avoid the usual injury to the essential and delicate hydrogel constituent. The nearly complete drying of clay renders re-handling, wetting down, and tempering necessary, and these operations, as usually carried out, are commonly erratic, on account of insufficient time being allowed, and the varying water content of the prepared dust. The following plan was developed so that better dust could be prepared more rapidly at less expense and with a more accurately controlled moisture—body ratio.

In preparing clay for working in the plastic condition the pebble mill is now very commonly used, and those using these mills have experienced advantages commensurate with the extra outlay. There is no reason against, and several good reasons for, the use of a mill in preparing slip intended for dust press operations. For this purpose I would recommend the continuous mill of the Hardinge type equipped with a self feeding device. Some misgiving was felt as to the uniformity of the slip delivered; would the mixture be complete, or would the easily supported clay particles be discharged more readily than the spar or flint? Would the difference in specific gravity of the materials influence the result unfavorably? Would the vegetable matter, small pieces of wood and the like do harm if milled up with the body?

So far as segregation in any form is concerned there need be no concern as the slip produced is perfectly uniform. Differences in specific gravity of the several constituents of the mix need give no concern as the gravities vary only between 2.58 and 2.65. Other proof of this, if needed, can be found in the fact that lithopone consisting of barium sulphide and zinc oxide has for some years been ground in a 60 x 22 cone type mill to a fineness of 96 per cent through a 200 mesh screen. When these mills are used in the mining industry it is necessary to use Dorr or other classifiers to separate fines of very great specific gravity differences.

In regard to chips of wood and other vegetable matter: it is astonishing how little effect a pebble mill will have on moderately soft material—corks, pieces of wood, rubber pump valves, intentionally put into mills, have sustained remarkably little abrasion on even long mill runs. On one occasion a four fold 12-inch ivory pocket rule was accidently included in a mill charge which ran 8 hours. Even this did not suffice to completely erase the marks on the rule; no other damage was noted except a very slight rounding of the edges—even the German silver end pieces and hinges suffered no injury.

The mill should discharge directly through a strainer into the electro-magnet box and thence flow directly to the lawn. The usual agitator would receive the slip from the lawn, followed by the customary filter pressing operation, which however, should be pressed up pretty well so as to give a cake carrying as little water as possible, and as small a soft core as practicable—if this is not removed.

Ordinarily the clay on leaving the presses will contain from 21–22 per cent water on the wet basis. In common current practice this clay would be dried, then wetted down, tempered, aged and ground. Instead of drying out so much water a great economy of time and steam can be effected and better dust obtained if the clay is put into a drier and only so much water dried out as it is necessary to remove for the desired end in view, *viz.*, a product containing about 16 per cent water. This means the removal of only 5–7 per cent of water. That this is not only possible but also highly desirable is attested by the results.

Two hundred and twenty-one pounds of freshly pressed leaves were weighed up on a rack and put into an ordinary dry room with steam coils running around the sides—direct weighings showed that sufficient moisture had been removed in $5^1/_4$ hours after which period the clay was immediately disintegrated and pressed into bushings. The pressman volunteered approval of the dust (which in itself is noteworthy). The pressed bushings were dried, cleaned, glazed and fired as usual and produced very good ware. It is well to note that in drying clay the first few per cents of water are the easiest of all to remove. If properly controlled an ordinary dry room may be operated quite successfully. Under proper care the filter presses may be made to deliver leaves of very constant average moisture content which renders dry room operation more easy and certain.

In another experiment 250 pounds of press leaves were treated in the same way taking again $5^1/_4$ hours to dry sufficiently and the results were entirely satisfactory in every way.

Clay so handled seems to be a little easier on the dies and fills out better although no tests have been made to see if the more difficult pieces could be made better with this clay. It may be safely predicted that an advantage in this respect would be gained also. A further drying test was made using a commercial humidity drier which required $6^1/_2$ hours to reduce the moisture from 21.9 per cent to 16 per cent and tests showed that the clay was delivered very uniformly indeed.

Supposing now we wish a clay having 16 per cent of moisture: it is necessary to remove from 106.3 pounds of wet clay, 6.3 pounds of water to yield 100 pounds of dust carrying the predetermined 16 per cent moisture. A universally felt difficulty in drying clay at high speed is the difficulty of establishing and maintaining even distribution and a practical industrial device that can be regulated and depended upon to do this is very desirable. As we know, the disintegrator is likewise a pretty good fan. As it disintegrates and delivers the clay it also delivers considerable air which, experiment has shown, has very little drying effect on the dust. Now a good high speed disintegrator with properly inclined blades will disintegrate clay direct from the press provided the moisture is not much in excess of 21 per cent. A machine having 6 blades and travelling 1800 R.P.M. with a 26-inch rotor did this quite nicely.

By applying hot blast in a suitable manner to the clay dust leaving the mill outlet the clay might be air supported at high temperature long enough to dry it sufficiently. This at first sight seems visionary but considering the enormously extended surface of the clay when broken into fine particles no insuperable difficulties present themselves. For example consider the beforementioned case where 6.3 pounds of water had to be removed from 106.3 pounds of wet clay. Suppose that we are using a fan delivering air at 192°F. This will take up slightly more than its own weight of water in becoming saturated at this temperature. The actual ratio is 0.0205 pound of air to 0.0254 pound of water; therefore we should require 4099 cubic feet of air, theoretically, but allowing for unavoidable loss and necessary safety factor, we will assume an input of 8,000 cu. ft. of air at 192°F. To heat this air from 70°F to 192°F will require between 1200 and 1300

B.t.u. or in terms of coal it is about equivalent to one pound of fairly good coal. Now the drying of press leaves in drying rooms is not nearly so efficient as this because of the enormous losses incurred, but the present toleration of these losses, is no argument for a continuation of such wasteful methods. Indeed the modern spirit of conservation demands that such methods be abandoned.

The procedure here suggested is very much like that successfully practiced in the preparation of milk powder; in this industry the milk is concentrated in vacuum evaporators till a certain predetermined density has been attained, at which time it is discharged with the aid of a blast into a large space. This operation produces a cloud which on settling, is the milk powder of commerce. Several considerations brought about this very beautiful industrial method, chief of which was the fact, that by this means the undesirable flavor brought about by too high concentration in the liquid state is avoided. The sudden exposure of the hot, thick milk in a finely divided state causes the final removal of moisture that changes the liquid suddenly into a powder; this sudden evaporation causes also a sudden cooling which is one desirable feature of the process.

The problems of producing milk dust and clay dust by this process are quite closely analogous, the clay problem being far the easier. It should be borne in mind that while the air is assumed to be at 192°F the clay would never approach this temperature as it would perform the wet bulb function of the hygrometer. The arrangement, proportions, and construction of the suggested drying shafts need not be dealt with here, as they would depend largely on local circumstances.

In a plant producing slip and dust by the methods here outlined the time saving would be very material. The following figures have already been obtained for one ton of clay mix figured dry.

	Hrs.	Min.
Milling	1	. ,
Lawning	0	50
Filter pressing	1	10
Drying (ordinary drier)	5	15
Disintegrating	0	30
	8	45

Eight hours and 45 minutes from bin to press room. If the dust is made directly from the press cake at least $4^1/_2$ hours could be deducted from this figure making the time for the clay in process four hours and fifteen minutes with clay dust coming along at the rate of 2320 pounds per hour on the basis of the size of the mill assumed together with its complement of lawn, filter presses and disintegrator. This would make it easily possible to place pressed ware in the dry rooms the same day that the clay, etc., was made into slip.

It is important to bear in mind that dust made in this way is considerably better than dust as ordinarily made. There would be better time made at the presses, less loss, less scrap and in the trucking and cleaning less breakage would be incurred and better ware secured. The only point that has not been experimentally established is the hot air blast drying and it would appear that any pottery would be more than justified in incurring the necessary expense involved in standardizing this one feature in view of the economies already demonstrated.

A SMALL GLASS TANK[1]

By H. T. Bellamy

ABSTRACT

The construction of the furnace is shown in the figure. It is fed from the 3 burners and uses about 24,000 cu. ft. of B.t.u. gas per 24 hours. It successfully melts high lead crystal, alabaster, opal, gold ruby opalescent, and green opalescent glasses.

The small glass tank to be described was built to be used in place of small pot furnaces for the manufacture of lead glasses. An output of about 500 pounds per day was desired and a melting chamber of this capacity was devised with standard tank blocks. The method of heating was given special consideration, for the strong assertions in the literature, that lead glass can not be melted in open pots or in tanks without discoloration, raised some uncertainty as to the success of the furnace.

We had made quite a variety of lead glasses in small open pots with only occasional signs of discoloration, but the greater area of glass exposed to the flame and to the products of combustion would of course tend to increase the reduction of the glass by the gases. It was decided to fire the furnace in such a manner that combustion might be as complete as practicable. Uncarburetted blue water gas was the fuel available and various systems of premixing air with this gas were considered. The Surface Combustion Company's equipment was finally decided upon. In this system the gas pressure is boosted to 10 or 12 pounds by a water-sealed pump. A valve and a gauge at each burner control the distribution of the gas. As the gas passes through the burner nozzle into a throat at high velocity, the pressure energy is transformed into velocity energy and air is induced into the throat through an adjustable shutter. The gas and air mixture then goes through a Venturi tube to facilitate thorough mixing before passing on to the burners.

[1] Received January 25, 1922.

To obtain the best combustion, especially at low temperatures, even with the proper mixture of gas and air, the gases issuing from the burner should be obstructed in some manner such as by impinging on or brushing against a surface or by the impact of opposing flames. It was at first planned to have the flames from burners on opposite sides meet a few inches above the surface of the glass. This idea was abandoned on account of the difficulty of accurate adjustment of opposing burners, and in its place was substituted the plan of inclining the burners at an angle of 30° from the horizontal so that the flames would brush against the arch. This scheme was followed when the furnace was installed and has given very satisfactory results. The furnace was first built with five burners staggered, two on one side and three on the

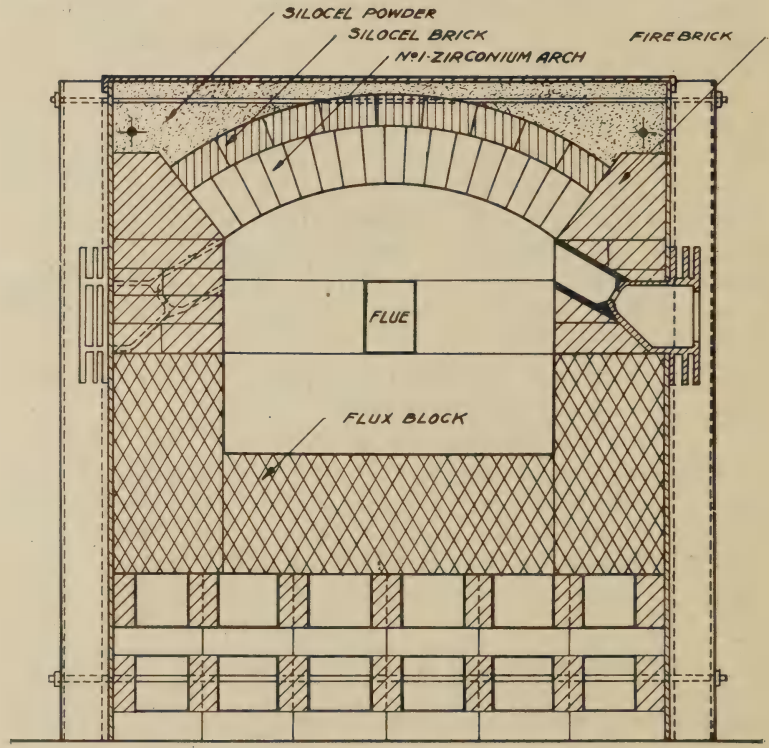

FIG. 1.

other but later two of the latter were removed, as three burners were found to be adequate.

The accompanying sketch is a cross section of the furnace as it was put into service. The first arch, built of silica brick, spalled and cracked badly on heating up. The silica brick were replaced with an arch of zirconium silicate brick, laid in zirconium silicate containing about 5% clay. This arch has been in service about one year and is still in very good condition. When it is necessary to replace corroded tank blocks, the arch is removed brick by brick and set up again. This is possible because there is no fluxing of the bonding material or the brick.

The time required to bring the furnace up to glass melting temperature depends on the moisture in the refractories. A newly constructed furnace should not be heated up in less than four days but thereafter the furnace may be cooled off and heated up over the week end without greatly increasing the depreciation. This feature is quite an advantage in the making of glass periodically without pot arches. It permits the making of repairs on the furnace equipment or the fuel and power lines without an excessive loss of time in bringing the furnace up to temperature.

The operator controls the temperature and combustion conditions of the furnace with a valve in the gas line and a shutter on the burner. At each burner are spring gauges sufficiently sensitive to permit adjustment to fractions of an ounce. The gas pressure indicated by the gauge in the by-pass is quite constant and with the accurate adjustment of burners to a predetermined pressure, a very constant temperature is maintained for long periods without attendance.

In operating the furnace, the batch is shoveled into the tank at intervals until the melted glass is up to the glass line giving a depth of seven inches when the tank blocks are first put in service. This depth increases as the bottom blocks are dissolved by the glass. The initial cubical content of the glass melting space is about $4^1/_2$ cubic feet. We have melted in this tank high lead crystal glass, alabaster, opal, gold ruby opalescent and green opalescent glasses. Occasionally there is a slight tinge of green to the crystal and alabaster glasses due apparently to too rich gas mixture. Accurate records on the gas consumption are not available, but from the data on hand the fuel required per 24 hour period is approximately 24,000 cubic feet of 300 B.t.u. gas.

Manufacturing Development Division
Hawthorne Works
Western Electric Company, Inc.

CORRECTION

"A Comparative Study of American and German Quartzites as Raw Materials for the Silica Brick Industry," by K. Endell (*This Jour.*, **4,** 956–57(1921)). The cuts on pages 956 and 957 should be interchanged.

JOURNAL
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AMERICAN CERAMIC SOCIETY

A monthly Journal devoted to the arts and sciences related to the silicate industries.

Editor: Ross C. Purdy; **Associate Editors:** L. E. Barringer, Chester H. Jones, R. L. Clare, E. P. Poste, H. Ries, F. H. Rhead, R. B. Sosman, R. T. Stull, E. W. Tillotson

Vol. 5 **April, 1922** **No. 4**

EDITORIALS

THE CHEMISTRY AND PHYSICS OF HIGH TEMPERATURES

The importance of the economical production and exact control of high temperatures to the industrial life of a nation can scarcely be over-emphasized. An English writer has recently gone so far as to state that "the future industrial success of any country will largely depend upon the extent to which it develops high temperature processes." The interest of the ceramic profession in this subject is two-fold. In the first place it has a primary interest arising from the fact that practically all of the ceramic industries belong themselves to the class of high temperature industries and all matters relating to the economical production and control of high temperature are therefore of paramount importance to the profession. In the second place all high temperature industries are dependent upon the ceramic profession for their supplies of that *sine qua non* of high temperature processes, refractory materials.

It is, therefore, not sufficient that the ceramic engineer be thoroughly conversant with the chemistry and physics of the manufacture of refractory materials. If he is to be of the greatest assistance to the high temperature industries which he serves, he must be familiar also with the chemistry of these industries because the refractories which he undertakes to produce must be capable not only of withstanding high temperatures alone but capable also of withstanding a variety of chemical influences. Moreover, the refractory must not introduce harmful materials into the manufactured products. The ceramic profession has therefore a vital interest in the whole field of high temperature research.

Among the non-ceramic industries which employ high temperatures may be mentioned the coke industry with its numerous by-products, the gas industry, the fixed nitrogen industries, the electric furnace industries and nearly all of the metallurgical industries. High temperature chemistry and physics is thus far-reaching in its importance to modern civilization and is an attractive field for the investigator. Perhaps some millionaire (?) brick manufacturer will sometime wish to establish a permanent memorial by founding and endowing an institute for research in the chemistry and physics of high temperatures. Such an institution would be a great boon to all industries having high temperature problems to meet.

1922 CONVENTION A RECORD

The 24th Annual Convention held February 27 to March 3, inclusive, at St. Louis, Missouri, was a record breaker in more than one respect. The attendance was 417, registered; original papers on the program were 164, aside from the 22 which were listed as having been previously published and to be discussed; the entertainment furnished by the local committee was replete with novel and highly pleasing numbers; the meetings of the seven Divisions and those of the general sessions were conducted on schedule and with a smoothness that was unusual, and harmony and singleness of purpose was in every heart, mind and act. Too much praise can not be given to the local committee for their superb management.

By divisions the attendance was as follows: Art Division, 25; Enamel Division, 87; Glass Division, 55; Heavy Clay Products Division, 67; Refractories Division, 82; Terra Cotta Division, 33; White Wares Division, 65; making a total of 414.

Officers elected for the year 1922:

Frank H. Riddle, *President*
E. Ward Tillotson, *Vice-President*
R. K. Hursh, *Treasurer*
B. E. Salisbury, *Trustee*

The other members of the Board are R. H. Minton, F. K. Pence, F. B. Qrtman, R. M. Howe.

ORIGINAL PAPERS AND DISCUSSIONS

THE INFLUENCE OF GRIND AND BURN ON THE CHARACTERISTICS OF SILICA BRICK[1]

By R. M. Howe and W. R. Kerr[2]

ABSTRACT

Finer grinding improves the appearance of the brick and increases their strength somewhat but not in any marked degree, within the commercial limits of grinding. A grinding of from 15 to 20 minutes seems most desirable. The time of grinding does not affect the porosity appreciably. The firing temperature is the principal factor governing the final strength and also the permanent residual expansion. The maximum temperature cone 19, yielded the highest strength and the lowest expansion.

An earlier investigation showed that 17 standard brands of commercial silica brick possessed moduli of rupture varying from 401 to 921 pounds per square inch. Certain of these brick were made to meet special conditions where high strength was unnecessary. In other cases the variation between brands was entirely due to different manufacturing conditions. The present investigation was instigated to determine the effect of two very important steps in the process of manufacture—grinding and burning.

The samples used in this investigation were made by taking mud from the same batch after grinding for 10, 15 and 20 minutes. Samples of each grind were burned at each of six temperatures ranging from cone 11 to cone 19.

McDowell[3] has already reported the results of a similar investiga-

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[1] Received Jan. 30, 1922.

[2] Fellows, Refractories Manufacturers' Association Fellowship 5, Mellon Institute of Industrial Research, University of Pittsburgh, Pittsburgh, Pa.

[3] "A Study of the Silica Refractories," G. S. McDowell, *Bull. Am. Inst. Mining Eng.*, **1916**, 2019.

tion, although the same procedure was not involved. Instead of burning different samples from cones 11 to 19 he burned the same samples one, two, or three times at cone 14 or 15. He reported that "the fine grind shows little if any advantage over the regular grind," "there is an advantage in burning the brick a second time," and "it is probable that stronger brick would be produced by maintaining the maximum temperature a greater length of time during a single burn than by resorting to repeated burning."

The effect of time upon the grind of the mud is shown by Table I.

TABLE I—SCREEN ANALYSES OF SILICA MUD AFTER 10, 15 AND 20 MINUTE GRINDS

Time of grind in minutes	10	15	20
Remaining on 10 mesh	17.8%	10.0%	3.0%
Remaining on 20 mesh	6.0%	8.0%	7.6%
Remaining on 40 mesh	10.7%	11.5%	12.5%
Remaining on 60 mesh	17.2%	19.0%	18.5%
Remaining on 80 mesh	12.0%	12.7%	13.0%
Remaining on 100 mesh	5.0%	5.2%	6.0%
Remaining on 120 mesh	3.8%	5.0%	4.8%
Remaining on 140 mesh	.5%	.5%	.5%
Passing through 140 mesh	27.0%	28.1%	34.1%

The effect of the grind and burn upon the modulus of rupture is shown in Table II. Each of the figures in columns 2, 3 and 4 represents an average of at least seven observations. The figures in the fifth column represent the average strengths of 21 brick of 3 grinds burned at the indicated temperature. The fig-

TABLE II—INFLUENCE OF GRIND AND BURN UPON THE MODULUS OF RUPTURE OF SILICA BRICK

Temperature of burn in cones	Time of grind in minutes 10	15	20	Average modulus of rupture for all grinds at each cone
11	295	285	330	303
14–15	324	400	381	368
16–17	436	372	523	444
17	526	605	585	572
18	525	513	581	533
19	531	618	694	514
Average modulus of rupture for each grind at all cones	440	446	499	

ures in the bottom row of this table (II) represent the average strengths of 42 samples of each grind burned at 6 different temperatures. Consequently these last two sets of figures are particularly significant.

Table III and IV are compiled in the same way as Table II.

TABLE III—INFLUENCE OF GRIND AND BURN UPON THE SPECIFIC GRAVITY OF SILICA BRICK

Temperature of burn in cones	Time of grind in minutes 10	15	20	Average specific gravity for all grinds at each cone
11	2.49	2.52	2.50	2.50
14–15	2.38	2.39	2.38	2.38
16–17	2.36	2.35	2.36	2.36
17	2.33	2.33	2.33	2.33
18	2.31	2.31	2.32	2.31
19	2.30	2.31	2.30	2.30
Average specific gravity for each grind at all cones	2.362	2.368	2.365	....

They refer to the porosity and specific gravity of the various samples.

Tables V and VI combine the average results expressed in Tables

TABLE IV—INFLUENCE OF GRIND AND BURN UPON THE POROSITY OF SILICA BRICK

Temperature of burn in cones	Time of grind in minutes 10	15	20	Average porosity for all grinds at each cone
11	27.15	28.46	28.13	27.91
14–15	27.27	28.19	29.45	28.30
16–17	26.68	28.40	29.08	28.05
17	26.90	26.95	30.40	23.08
18	25.15	26.78	28.23	26.72
19	28.00	27.80	26.96	27.59
Average porosity for each grind at all cones	26.86	27.76	28.71	.....

TABLE V—INFLUENCE OF GRIND UPON SEVERAL CHARACTERISTICS OF SILICA BRICK

	Average value for all burns and one grind			
Time of grind in minutes	Specific gravity	Residual permanent expansion	Modulus of rupture	Per cent porosity
10	2.362	1.5%	440	26.86
15	2.368	1.6%	416	27.76
20	2.365	1.6%	499	28.71

II, III, and IV. Each of the values in Tables V and VI therefore represents the average of from 21 to 42 observations. The permanent expansion remaining in the brick has been calculated from the tables of F. A. Harvey and E. N. McGee[1] and these values are also included.

Table V shows conclusively that the time of grinding Medina Quartzite may be varied 100 per cent without seriously changing the strength of the bricks. The texture, to be sure, varied to the degree shown in Table I and this characteristic affected the workmanship somewhat. Generally speaking, the bricks of the finer grinds had better appearances. The modulus of rupture, however, varied only 14 per cent, the porosity 2 per cent, and the expansion practically none. These conclusions are deduced from this table in preference to the others because each figure represents so many observations.

TABLE VI—INFLUENCE OF BURN UPON SEVERAL CHARACTERISTICS OF SILICA BRICK

	Average value for all grinds at each cone			
Temperature of burn in cones	Specific gravity	Residual permanent expansion	Modulus of rupture	Per cent porosity
11	2.50	4.2%	303	27.91
14–15	2.38	2.0%	358	28.30
16–17	2.35	1.3%	444	28.05
17	2.33	.8%	572	28.08
18	2.31	.4%	533	26.72
19	2.30	.2%	614	27.59

Table VI, however, shows that the burning temperature exerts a tremendous influence upon the characteristics of the finished brick. The porosity was not affected by the burning temperature but the expansion and strength varied more than 100 per cent over a range of 6 cones.

A second lot of brick was made from similar quartzite and the general method of procedure was the same. The grinds included 6, 13, and 20 minute periods and therefore covered a broader range. The burns were restricted to one at cone 14–15, one at cone 17, and one at cone 19. The screen analyses of the mud and the average physical characteristics of the brick are given in Tables VII and VIII. The results of the tests made upon the second lot of samples confirmed those already reported, although the effect of grinding 6 minutes should be discussed more in detail.

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[1] "Testing Coke Oven Refractories," Harvey and McGee, *This Jour.*, **4,** 475 (1921).

TABLE VII—EFFECT OF GRIND UPON MUD AND BRICK OF SERIES II

Time of grind in minutes		6	13	20
Per cent mud on 10 mesh		29.7	19.5	13.0
Per cent mud on 20 mesh		3.7	4.0	4.0
Per cent mud on 40 mesh		7.5	7.3	7.1
Per cent mud on 60 mesh		16.8	19.8	21.3
Per cent mud on 80 mesh		12.4	14.4	15.7
Per cent mud on 100 mesh		5.0	5.6	5.8
Per cent mud on 120 mesh		3.3	4.0	3.0
Per cent mud on 140 mesh		.3	.3	.3
Per cent through 140 mesh		21.3	25.1	28.6
Average values for brick of one grind and three burns (cone 15 to cone 19)	Modulus of rupture	389	655	701
	Specific gravity	2.340	2.343	2.343
	Residual permanent expansion	.00	1.20	1.20
	Per cent porosity	26.70	27.94	25.53

TABLE VIII—EFFECT OF BURN UPON CHARACTERISTICS OF BRICK OF SERIES II

	Average value for all grinds at each cone			
Temperature of burn in cones	Specific gravity	Residual permanent expansion	Modulus of rupture	Per cent porosity
14–15	2.38	2.0%	533	26.38
17	2.33	.8%	590	26.49
19	2.32	.6%	622	27.30

The results of all the tests were plotted so as to study the influence of the time of grinding upon the strengths of the brick. It developed that there was a slight increase in strength (14 per cent) when the first mix was ground 20 minutes instead of 10. It also developed that there was a marked increase in strength (68 per cent) when the grind of the second lot was increased from 6 to 13 minutes. No important increase (7 per cent) was noted when the grind was extended from 13 to 20 minutes. It might be stated, however, that the 10, 13, 15, and 20 minute grinds for this material are within the limits of commercial work which the 6 minute grind is not.

An attempt was then made to determine to what degree the mud should be ground in order to produce a strong brick. The mixes studied were properly ground after 10 and 13 minutes but were not sufficiently ground after 6 minutes. Other raw materials, however, grind with more or less difficulty. The terms fine, coarse, and medium are not exact. When the screen analyses were studied it was found that the 10 and 13 minute grinds gave muds with remarkably similar analyses. These analyses follow:

TABLE IX

Time of grind in minutes	10	13
Per cent on 10 mesh	17.8	19.5
Per cent on 20 mesh	6.0	4.0
Per cent on 40 mesh	10.8	7.3
Per cent on 60 mesh	17.2	19.8
Per cent on 80 mesh	12.0	14.4
Per cent on 100 mesh	5.0	5.6
Per cent on 120 mesh	3.8	4.0
Per cent on 140 mesh	.5	.3
Through 140 mesh	27.0	25.1

While this remarkable similarity may be simply a coincidence it is known that when silica mud has an analysis similar to these little additional strength can be gained by longer grinding. When the mud is coarser (as shown by the analysis of the 6 minute grind) the bricks may be weak because of insufficient grinding.

From the practical standpoint it might be stated that changes in commercial grinds as now made, do not seriously change the strength of silica bricks. The porosity of silica bricks is not seriously affected by the grind. The strength and amount of residual expansion of silica bricks is controlled almost entirely by the burning temperature.

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RESISTANCE TESTS ON FIRE BRICKS UNDER LOADS AT HIGH TEMPERATURES[1]

By E. Sieurin and Fredr. Carlsson[2]

Experiments carried out by B. Kjellgren

ABSTRACT

Method.—Mixtures of fine ground china clay and ball clay with grog (called by the author "chamotte") of the same materials were made into 3 cm. cubes and subjected to a pressure of 2 kg. per sq. cm. at temperatures which sufficed to bring about a linear contraction of 0.3 per cent in 2 hours. Definite quantities of silica, alumina, ferric oxide, lime and magnesia were added and both the deformation and the usual softening points determined.

Results.—Even very small amounts of the oxides of iron, calcium and magnesium brought about a considerable reduction in the resistance to pressure. A minimum in the resistance was observed with silica contents between 60–70 per cent, which does not correspond to the minimum softening point or melting point of clay-silica mixtures. Additions of alumina increased the temperature required to deform the specimens but with high alumina content mechanical failure due to lack of bonding material occurred. For many purposes clay fire brick will have to be replaced by more resistant materials, such as brick made from silica, aluminous mixtures and silicon carbide.

Formerly, when judging the properties of fire bricks, great importance was attached to the melting point (shown by Seger cones) and to the chemical composition, as regards ordinary fire bricks to the alumina contents particularly. Experience, however, has shown that such determinations do not fully indicate the properties of these refractory products. It has become more and more evident that the importance of determining the melting points by Seger cones has been over-estimated. This is especially the case with fire clay material owing to the fact that this material shows a considerable softening interval between 300° and 400°C.

Investigators, therefore, soon endeavored to find other methods which would better illustrate the real properties of the materials

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[1] Received December 31, 1921.

[2] Communicated by the Laboratory of the Höganäs Works at Höganäs, Sweden.

and they discovered a particularly good method for this purpose in the determination of the resistance under load at high temperatures.[1]

In carrying out such investigations it will frequently be noticed that even slight variations in the chemical composition cause important changes in the resistance under load at high temperatures. It may therefore be of interest to examine the influence of variations in the chemical composition. The following investigations have been carried out with this object.

As is known a fire brick is made of a mixture of raw clay and grog. Obviously when investigating the influence of a substance upon the properties of a material, this substance must be extremely intimately mixed with the binding clay as well as with the grog. These investigations were therefore carried out in such a manner that a normal clay of known composition was minutely wet-ground during 12 hours in a ball mill along with the substance being examined. By means of screening, it was found that no residue was left after passing through a 10,000 meshes per square centimeter.

One part of this very finely ground mixture was burnt to chamotte at cone 14 (1410 °C), then crushed and screened partly to grains between screens No. 4 and No. 20 (*i. e.*, 4 and 20 meshes per lineal inch, respectively), partly to a product finer than No. 7 (*i. e.*, 7 meshes per lineal inch). The different kinds of chamotte were then mixed with raw clay in the proportions of one part chamotte to one part raw clay and cubes a little more than 30 mm. square were formed with this mixture. Cubes were made of each mixture partly with chamotte screened through 7 meshes and partly with chamotte in grains between 4 and 20 meshes, *i. e.*, with the fine powder sieved away. These cubes were then burnt at cone 14 and afterwards cut as exactly as possible to 30 mm. square.

Certain quantities of SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO were added to the raw mixture. With each mixture the fusion point was determined in the usual manner by cone as was also the softening temperature. The latter is defined as "the temperature at which the test cube exposed during two hours to a load of 2 kilos per square cm. experiences a lineal contraction of 0.3 per cent of the original length."

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[1] Cf. K. Endell, "Über das Verhalten feuerfester Steine unter Belastung bei hohen Temperaturen," *Stahl u. Eisen*, **1921** H. 1.

The heat took place in an electric resistance furnace, the resistor consisting of granular (14–29 mesh) retort carbon contained between two vertical coaxial tubes of carborundum.

A carborundum rod with its upper surface at the center of the furnace served as the support for the test tube and the Seger cones. Pressure was applied to the test piece by means of a loaded rod of carborundum.

Investigations proceeded simultaneously in 4 furnaces, connected as shown in Fig. 1, so that an exact regulation of the electric current could be arranged by means of a liquid resistance. The main current from the transformer was regulated by means of a water-cooled iron wire resistance. The furnaces were coupled on a transformer with a secondary tension of 110 volts; consequently each furnace received about 55 volts. The load for each furnace was about 35 kw. at 1500°C and about 20 kw. at 1350°C.

The tests were carried out in these comparatively large furnaces in order to enable the temperature to be kept as steady as possible. The temperature was determined by means of Seger cones which were placed in the furnaces at certain intervals.

Coupling scheme.

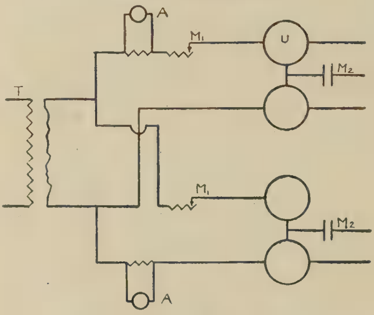


FIG. 1.—T, Transformer; A, Ampèremeter; M_1, Iron wire resistance; M_2, Liquid resistance; U, Furnace.

The tubes, as well as the pressing rod of silicon carbide proved to be extremely suitable for the purpose. The tubes were used during months of testing and they were often suddenly cooled without cracking. When the cubes were changed, the pressing rods were frequently taken out while white hot, but in spite of this they did not crack.

The temperature was regulated in the following manner: For the determination of the desired temperature, for instance that of cone 10, the cones numbers 9, 10 and 11 were set down in the furnace whereupon cone 9 bent down suddenly, cone 10 bent little by little until the point touched the bed, while cone 11 did not bend. The furnace being so exactly regulated that cone 11 remained unbent, the temperature was considered as having been reached. During the carrying out of the experiments, new cones numbers 9 and 10 were set down every hour, and in this manner the temperature could easily be kept practically constant during each testing period. The furnaces were often running day and night in order to avoid the heating periods. As showing the exactness of the regulation of the temperature it may be stated that during a period of 6 to 8 hours the point of each new cone 10 touched the bed after one hour exactly.

In order to determine the softening temperature for a test mixture, a series of pressure tests was carried out, first at high temperature and then at temperatures lower and lower, until, finally, the test cube was no longer compressed. The softening temperature was considered to have been reached at a contraction of 0.3 per cent. For instance, on pressing the original material, the following results were obtained:

Cone	Per cent contraction at the end of 2 hours
11	2.9
11	3.2
10	0.9
10	1.2
9	0.3
9	0.2
8	0.0
8	0.0

The softening temperature is consequently to be found between cone 9 and cone 10, but nearer cone 9.

The primary mass consisting of 1 part blue clay and 1 part washed china clay, gave the following analysis (after calcination).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	Total
54.52	43.04	0.89	0.68	traces	0.78	0.0	99.91

Fusion point given as cone 34 (1750°C).

To this mixture certain quantities of SiO_2, Al_2O_3, Fe_2O_3, CaO, and MgO were added in the purest possible form. The silicious material was added in the form of the purest quartz, the alumina, oxide of iron and magnesia in chemically pure form, and the lime as chemically pure precipitated chalk. The Seger formula was calculated from the original analysis and on the basis of this a certain number of moles of the different oxides were added (see the various tables). The percentages were all *calculated.*

Increase of the Percentage of Silica

The silica was added in the form of quartz with SiO_2 content about 99 per cent.

The different mixtures and the results of the investigation are shown in Table I and Fig. 2. The underlined figures indicate the cones most nearly corresponding to the temperature in question.

TABLE I

Number of SiO_2 moles to the mixture	Percentage of SiO_2 in the raw clay	Percentage of SiO_2 in the mixture	Melting point given as cone	Softening temp. chamotte		Number of pressure tests
				4–20 mesh	7 mesh	
0	54.52	54.52	*34*–35	*8*–9	9	20
5	54.52	57.2	33–*34*	7–*8*	8–*9*	24
15	54.52	61.6	32–*33*	*7*–8	*8*–9	18
30	54.52	66.7	31–*32*	*6a*–7	*7*–8	18
60	54.52	73.8	29–*30*	*8*–9	*9*–10	22
100	54.52	79.6	28–*29*	*10*–11	10–*11*	24
...	...	86.8	27–28	...	...	..
...	...	90.3	26–*27*	...	...	..
...	...	93.9	29–30	...	...	..
...	...	96.4	30	...	...	..

The results of the experiments are graphically shown in Fig. 2.

From this sketch it will be seen that a definite minimum for the softening temperature exists between 60 and 70% silica content. At 60 and 70% silica content the softening temperature is almost the same and, in both cases, exceeds the temperature for about 67% silica content by about 25 °C. The minimum for the softening temperature sets in consequently at a considerably lower percentage of silica (between 60 and 70 per cent) than for the cone melting point, for which the minimum lies at about 90 per cent of silica.

Admixture of SiO_2.

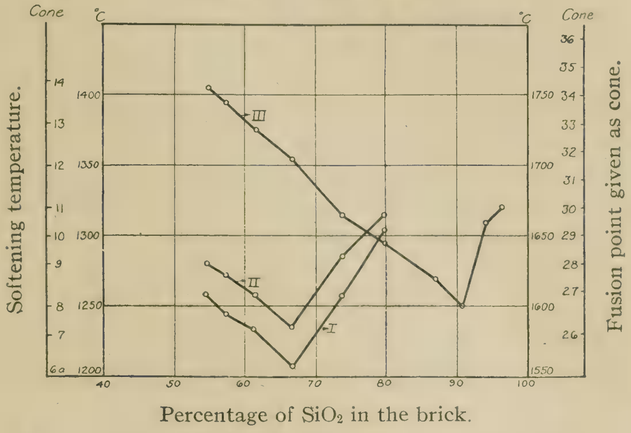


FIG. 2.—Curve I, Softening temperature chamotte 4–20 m.
Curve II, Softening temperature chamotte 7 m.
Curve III, Fusion point given as cone.

Admixture of Al_2O_3.

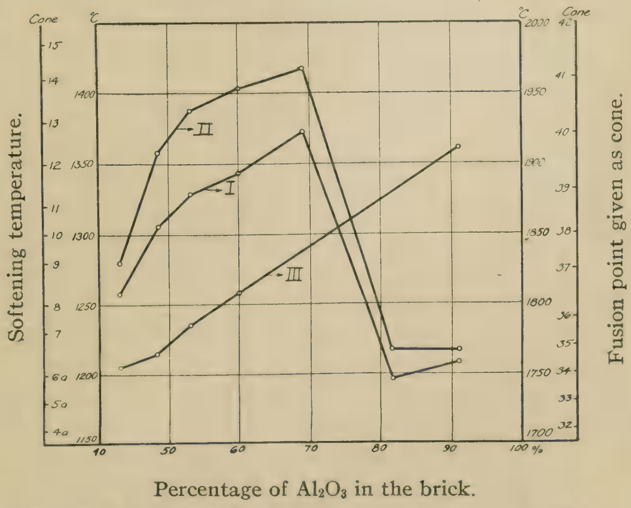


FIG. 3.—Curve I, Softening temperature chamotte 4–20 m.
Curve II, Softening temperature chamotte 7 m.
Curve III, Fusion point given as cone.

With a higher percentage of silica, the softening temperature rises rapidly, attaining about 1650°C when the percentage of SiO_2 reaches about 95 (*i. e.*, the usual average for silica bricks).

From the curves it will be seen that in all cases the coarse-grained mass gives a considerably lower softening temperature than the fine-grained mass, which is certainly due to the presence of certain hollows which cause a more rapid contraction. The fact that the coarse-grained mass shows a lower softening temperature was observed in most of the tests.

Increase of the Percentage of Alumina

Alumina was added in the form of calcined chemically pure alumina and the results obtained are shown in Table II and Fig. 4.

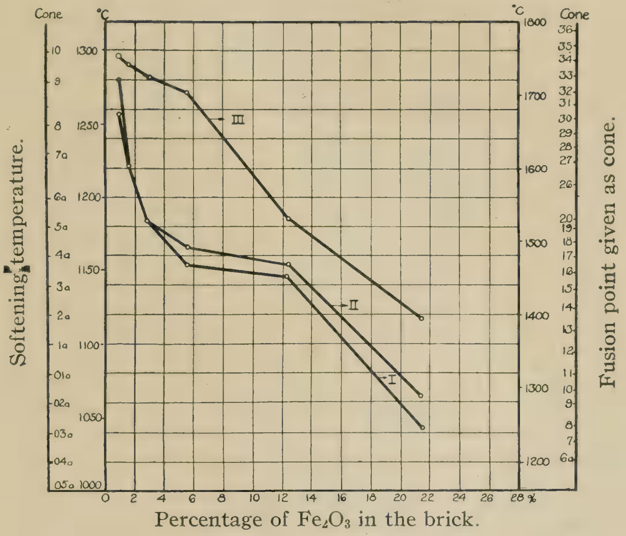
TABLE II

Number of Al_2O_3 moles added to mixture	Percentage of Al_2O_3 in the raw clay	Percentage of Al_2O_3 in the mixture	Melting point given as cone	Softening temp. chamotte 4–20 mesh	Softening temp. chamotte 7 mesh	Number of pressure tests
0	43.04	43.0	*34*–35	8–9	9	20
5	43.04	48.4	34–*35*	*10*–11	*12*–13	20
10	43.04	52.9	35–*36*	*11*–12	*13*–14	24
20	43.04	59.8	36	11–*12*	13–*14*	22
40	43.04	68.9	36	12–*13*	*14*–15	22
100	43.04	81.5	36	5a–*6a*	*6a*–7	28
250	43.04	90.8	39–*40*	*6a*–7	6a–7	28

With an increased percentage of alumina, the softening temperature rises continuously. The sudden fall noticed with a very high percentage of alumina (about 80 per cent Al_2O_3) is probably due to the fact that the small quantity of binding clay is not sufficient to keep the alumina grains together. It is not a real softening temperature which is observed here but a sudden collapse owing to the lack of binding material. As in Table I, the fine-grained mixture shows a considerably higher softening temperature than the coarse-grained.

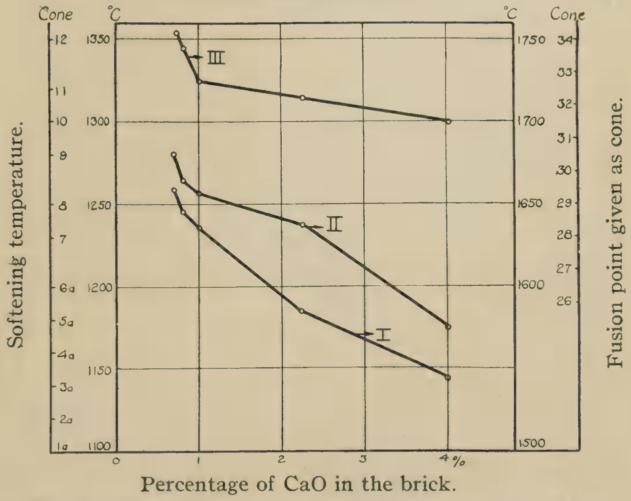
Increase of the Percentage of Oxide of Iron

Chemically pure oxide was added. The result of the investigations are shown in Table III and Fig. 5.



Admixture of Fe_2O_3.

FIG. 4.—Curve I, Softening temperature chamotte 4–20 m.
Curve II, Softening temperature chamotte 7 m.
Curve III, Fusion point given as cone.



Admixture of CaO.

FIG. 5.—Curve I, Softening temperature chamotte 4–20 m.
Curve II, Softening temperature chamotte 7 m.
Curve III, Fusion point given as cone.

TABLE III

Number of Fe_2O_3 moles added to the mixture	Percentage of Fe_2O_3 in the raw clay	Percentage of Fe_2O_3 in the mixture	Melting point given as cone	Softening temp. chamotte		Number of pressure tests
				4–20 mesh	7 mesh	
0	0.89	0.89	*34*–35	*8*–9	9	20
0.2	0.89	1.53	33–*34*	6a–*7*	6a–*7*	22
0.6	0.89	2.79	32–*33*	*5a*–6a	*5a*–6a	22
1.5	0.89	5.51	31–*32*	3a–*4a*	*4a*–5a	24
4.0	0.89	12.32	20 near	*3a*–4a	3a–*4a*	22
8.0	0.89	21.40	13–14	*03a*–02a	*02a*–01a	22

An increase of the percentage of iron oxide by 0.64 caused a lowering of the softening temperature of 50 °C. After this point the softening temperature declines more slowly so that it is nearly constant between 6 and 12 per cent Fe_2O_3, falling more rapidly if the percentage of iron oxide is further increased.

Curiously enough, this curve does not show the same difference between coarse and fine grains as do all the other mixtures.

Increase of the Percentage of Lime

The lime was added as chemically pure precipitated chalk. The results are given in Table IV and Fig. 6.

TABLE IV

Number of CaO moles added to the mixture	Percentage of CaO in the raw clay	Percentage of CaO in the mixture	Melting point given as cone	Softening temp. chamotte		Number of pressure tests
				4–20 mesh	7 mesh	
0	0.68	0.68	*34*–35	*8*–9	0	20
0.1	0.68	0.79	33–*34*	7–*8*	8–9	22
0.3	0.68	1.02	32–*33*	*7*–8	*8*–9	22
1.4	0.68	2.25	*32*–33	*5a*–6a	*7*–8	20
3.0	0.68	3.98	31–32	*3a*–4a	4a–*5a*	22

The softening temperature is considerably reduced by a slight increase of the lime content. For instance an increase of 0.11 per cent CaO causes the softening temperature to fall about 25 °C. With a further increase, the softening temperature falls less rapidly, although, of course, the extremely bad influence of this impurity is easily seen from the diagram.

As the strong influence of so small an increase of lime from 0.68 to 0.79 per cent is distinctly apparent, a material with a still smaller percentage of lime than the raw mixture will certainly show a much higher softening temperature. Investigations are now being made to ascertain the softening temperature with a lime content even lower than 0.68 per cent.

In this case also, the influence of the fineness of the grog may be distinctly observed.

Admixture of MgO.

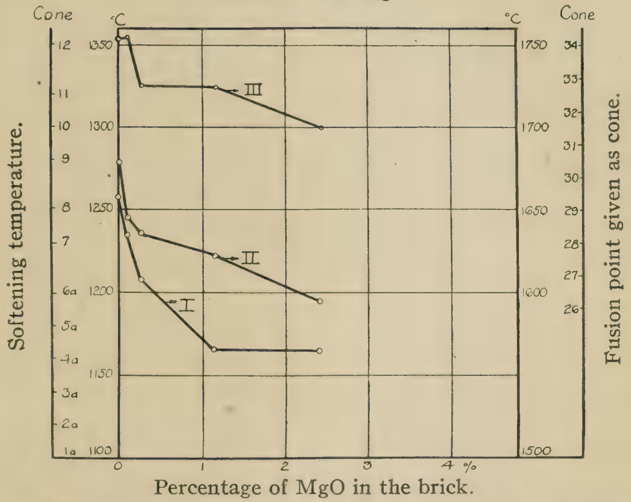


FIG. 6.—Curve I, Softening temperature chamotte 4–20 m.
Curve II, Softening temperature chamotte 7 m.
Curve III, Fusion point given as cone.

Increase of the Percentage of Magnesia

The results of the investigation are given in Table V and Fig. 7.

TABLE V

Number of MgO moles added to the mixture	Percentage of MgO in the raw clay	Percentage of MgO in the mixture	Melting point given as cone	Softening temp. chamotte 4–20 mesh	Softening temp. chamotte 7 mesh	Number of pressure tests
0	0.00	0.00	34–35	8–9	9	20
0.1	0.00	0.08	34–35	7–8	7–8	20
0.3	0.00	0.25	32–33	6a–7	7–8	18
1.4	0.00	1.14	32–33	4a–5a	6a–7	20
3.0	0.00	2.41	31–32	4a–5a	5a–6a	20

As in the case of lime, a slight increase in the percentage of magnesia has a strong influence in lowering the softening temperature, but to an even greater extent than with lime. Thus an increase of the percentage of MgO from 0 to 0.08% causes the softening temperature to fall from 1280° to 1240°C.

With 1 per cent of magnesia, the softening temperature is 1220°C for the fine-grained mixture, while 1 per cent of CaO reduces the softening temperature only to 1260°C.

In this instance also a great difference can be observed between coarse- and fine-grained masses.

CARBORUNDUM BRICK[1]

By M. F. Peters[2]

ABSTRACT

A study of carborundum-clay mixtures with reference to the relation between the proportioning and sizing of the constituents and the properties of the refractory as expressed by the tensile strength, the load test, the slagging and the spalling tests. For good working conditions the amount of clay must suffice to cover the grains of SiC. When subjected to crushing the linear compression varies as the second power of the percentage of carborundum. Oxidizing furnace conditions and the presence of iron oxide, lead oxide and lime reduce the resistance to slag action. The resistance to spalling depends upon the content of SiC, the tensile strength, the coefficient of expansion and the thermal conductivity of the clay. A formula is proposed for the estimation of the life of the carborundum refractories, and a theoretical explanation of their physical properties is offered.

I. Introduction

1. Outline of Discussion.—That carborundum can replace saggers, flint, dobies, and other grog materials in fire brick is still an open question, yet one, which seems to warrant considerable attention. While some work has been done along this line, very little has been published which covers the subject as thoroughly as desirable. In this paper an attempt has been made to present the general idea underlying the use and advantages of carborundum brick, thus making it possible to decide in advance the advisability of using this material under any given set of conditions. Below is given the outline which will be followed throughout this discussion.

- II. Mixtures.
- III. Methods adopted for testing carborundum bricks.
- IV. Development of a formula by which we may compare carborundum bricks with clay bricks.
- V. Fabrication of carborundum bricks.

[1] Received November 10, 1921.

[2] Published by permission of the Chief of Research, New Jersey Zinc Company.

VI. Results obtained from test bricks.

VII. Theoretical explanation for the physical properties of carborundum bricks.

VIII. General conclusions.

II. Mixtures

2. **Proper Sizing of Carborundum.**—As data is obtained on refractories it is being realized that the inert material plays a very important rôle. Not only must care be exercised in selecting a substance which has the proper chemical composition, but judgment must be used in sizing. From tests conducted by Fulton and Montgomery[1] using bodies which contained 50% St. Louis Fire Clay and 50% grog by weight, it was found that the modulus of rupture in the raw state increased from 6 to 100 mesh grog, and then decreased with the 200 mesh. In the burned state up to cone 15 the strength increased with decrease of grog size. The porosities at cone 15 were 10–13% for 6–14–35 mesh bodies, and 5–6% for 100–200 mesh bodies.

While strength is very desirable it must not be forgotten that certain refractories require a dense material capable of withstanding rapid changes in temperature. The first is obtained by the use of fine grog, which however, destroys the second. It has been found that refractories containing proper proportions of 8 to 40 mesh grog withstood the quenching test better than those with the finer sizes. Another bad feature in using fine grog is that the fusion point is lowered, and unless care is used in selecting materials the refractories may fail.

In dealing with carborundum, however, we have an entirely different material. In the first place, the temperature of decomposition is far above any temperature reached in the furnace, so that the fusion point of the brick will not be lowered by using the finer sizes. Again, the rate of spalling of carborundum brick is small, so that we should not expect much trouble from rapid changes in temperature. From the above it seems that by using carborundum we can obtain a very dense mass without the disadvantages which usually accompany other grogs.

Upon a second consideration, however, it may not be advantageous to use the finer sizes. Since one of the big arguments in favor of carborundum is its higher thermal conductivity it can be seen that the more carborundum and the less clay used the nearer will this condition be realized. Heat in passing through the brick must pass through both the clay and carborundum. Each particle of carborundum must be surrounded by clay, so that the heat will pass through what might be considered several layers of clay and carborundum. In case the carborundum is fine, the number of layers of clay will be great, the heat conductivity being thus impaired. On the other hand, if the material is coarse, the number of layers of clay will be small, and the conductivity great. Of course, if only one size of coarse material is used we will need considerable clay to fill the voids, but this can be remedied by adding sufficient fine carborundum. Our problem then is to so proportion the sizes of carborundum particles that we will obtain a mixture of maximum density, as it is very essential that the thermal conductivity of these brick be high. A few experiments will bring this out more clearly and show us what sizes should be mixed together.

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[1] "The Effect of Grog in Fire Clay Bodies," *Trans. Amer. Cer. Soc.*, **17,** 409.

If 100 grams of carborundum which has passed through 200 mesh is put into a graduated tube so that its volume may be accurately measured we find that it occupies 65 cc. As we continue to measure the volume of these mixes we find that as the size increases the volume decreases, and for 35 mesh the volume is 58 cc. per 100 grams. If now 30 grams of 28 mesh carborundum are mixed with 10 grams of each of the following, 35, 48, 65, 100, 150, 200, +200 mesh we find that its volume has been reduced to 48 cc., in other words, for a brick composed entirely of carborundum we can increase its weight $\frac{(65-48)}{48} = 35.4\%$. Since clay must be added as a bond these figures will change, the change tending to make this ratio greater. In the case of fine material 40% clay must be added while in the latter only 25% should be used. This percentage of clay will be discussed in the following section.

From the above it is quite evident that to increase the thermal conductivity the sizes should be so proportioned that we have a maximum amount of coarse, but sufficient fines must be added to fill the voids. It will be shown later that this mixture stood up the most satisfactorily during the test, and that this is the proper mixture from a theoretical standpoint.

3. Percentage of Clay to Add to Carborundum.—Whenever two substances are mixed in which one is the inert material and the other is the bond, it is necessary and sufficient to fulfill these two requirements: (1) cover each particle of inert material with bond, (2) fill the voids between these particles.

To accomplish the first and use a minimum amount of bond it is necessary to use a very coarse material, as the ratio of surface to volume is small. With a decrease in size, however, this increases very rapidly. To use a minimum amount of bond in the second case it requires a very fine material, for here the voids[1] are small. Since the quantity of bonding material is the sum of these two factors, and when the first case requires a minimum the second requires a maximum, or, vice versa, we know that there is some size where the sum of the two is a minimum. What seems to be a more reasonable solution than this is one in which we have a mixture of several sizes. In this case we have the coarse material requiring very little bond to cover its surface, while the smaller sizes fill up the voids. Perhaps the best method of answering this question is to follow out a few cases of proportioning sizes, together with the method adopted for calculating the quantity of clay required.

Method: When sufficient water is added to carborundum it wets the surface of each particle and fills the voids, the quantity of water varying with these two factors. The quantity of water is then a measure of the required volume of clay, for it distributes itself throughout the mix in the same manner as the bond. Knowing the specific gravity of clay (2.55) and the volume required, the product of these two factors will give the weight. Four problems will bring this out more fully.

(1)—It requires 27 cc. of water to cover 100 grams of carborundum which has passed through a 200 mesh screen. What weight of clay is required? What is the percentage of clay in the mixture?

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[1] If we have spherical particles of diameter A the ratio of volume to voids is a constant regardless of the values given to A. With carborundum the ratio of volume to voids is not a constant but increases with an increase in size. This is probably due to the irregular shape of the carborundum particles.

$27 \times 2.55 = 68.8$ grams of clay per 100 grams of carborundum or, 688 pounds of clay per 1000 pounds carborundum.

$$\frac{688}{1688} = 40.7\% \text{ clay in mix.}$$

(2)—Some coarse material required 32 cc. of water per 100 grams of carborundum. What weight of clay is required and what is the percentage of clay in the mixture?

$10 \times 32 \times 2.55 = 816$ pounds of clay per 1000 pounds of carborundum.

$$\frac{816}{1816} = 44.9\% \text{ clay in mix.}$$

(3)—The carborundum used in problem (2) was ground and made into bricks. It was found to require 17 cc. of water to cover 100 grams of the material. What weight of clay should be used per 1000 pounds of carborundum? What was the percentage of clay in the mixture?

$10 \times 17 \times 2.55 = 434$ pounds.

$$\frac{434}{1433} = 30.2\% \text{ clay in mix.}$$

(4)—When 30 grams of 28 mesh and 10 grams each of 35, 48, 65, 100, 150, 200, +200 mesh were mixed it was found to require 13 cc. of water. What weight of clay is required per 1000 pounds of carborundum? What per cent of the mix is clay?

$10 \times 2.55 \times 13 = 332$ pounds.

$$\frac{332}{1332} = 24.9\% \text{ clay.}$$

In using this method to determine what percentage of clay is required the following procedure is recommended: (*a*) Weigh up a definite weight of carborundum, say 100 grams. (*b*) Add 100 cc. of water. (*c*) Remove all entrapped air. (*d*) Allow to stand until settled. (*e*) Subtract water above carborundum from 100. (*f*) Multiply (100—water above carborundum) by 25.5 which gives number of pounds of clay to add to 1000 pounds of carborundum.

4. Tensile Strength of Various Mixtures of Carborundum and Clay.—In Fig. 1 we have a curve showing the relation between the tensile strength of various percentages of carborundum and Grand View Fire Clay. These briquettes were all mixed from the raw materials, rotted, moulded, dried and burned together at 1000°C. These tests show that as the percentage of carborundum is increased the tensile strength increases very rapidly at first, then remains practically constant and finally falls off very rapidly. In this particular case the maximum strength is obtained with approximately 45% carborundum. In mixtures of carborundum and certain ball clays the maximum tensile strength was obtained with 70% carborundum, so that it is impossible to say what proportions of carborundum should be used with any clay to obtain the maximum tensile strength, unless briquettes have actually been made and broken.

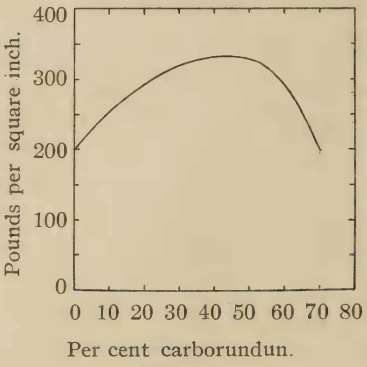

FIG. 1.

Tensile strength of Grand View fire clay.

III. Methods Adopted for Testing Carborundum Bricks

While there are a great many reasons for fire bricks failing it was thought that in this particular furnace where these bricks were used failure would be due to a combination of the decrease in resistance to deformation at high temperatures, slagging, and spalling.

It was found after the work had been completed that the abrasive action while small should have been considered. This will be discussed later.

5. Decrease in Resistance to Deformation at High Temperatures.—A measurement of the resistance to deformation at high temperatures of a refractory material is really a measure of the decrease in its viscosity.[1] These measurements were made using the furnace shown in Fig. 2 which is the improved Case Melting Furnace No. 24 of the Denver Fire Clay Company. It is heated by 2 low pressure burners using fuel oil. The burner is supplied by the same company. The brick to be tested is dried at 110°C for 5 hours, measured, and then placed upon a heavy carborundum brick held in place by carborundum cement. A half carborundum brick is placed upon the test brick and then high grade fire brick built up which extends through a hole in the cover.

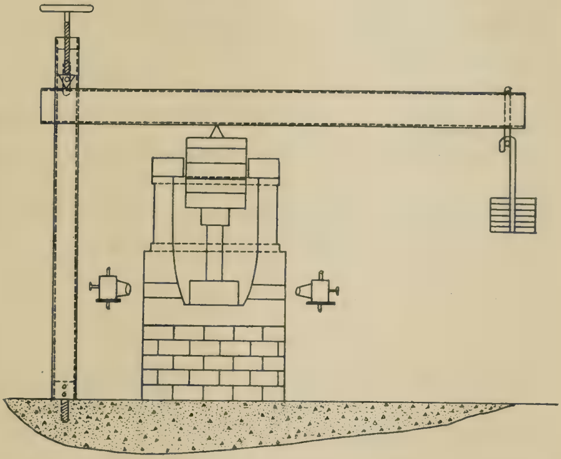

FIG. 2.

Upon the upper brick is placed a cast iron knife edge through which the load is applied by means of an I beam 6 feet long. The distance between the knife edge taking the upthrust and the fulcrum is 2 feet, and the distance between the fulcrum and the point of application of the load is 4 feet. The downward thrust at the fulcrum due to the weight of the beam was determined by means of a platform scale placed in the same position as the brick. The applied load consisted of circular iron plates and was also calibrated within the limits of the scales. The knife edge taking the upthrust acted against a screw so that the beam could be kept level throughout the test. The load upon the test brick was 50 pounds per square inch.

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[1] *Bur. Standards, Tech. Paper*, No. **7.** "The Testing of Clay Refractories with Special Reference to Their Load Carrying Capacity at Furnace Temperatures."

With the test brick in place, the temperature was raised to 1350°C at the rate of 6.50°C per minute. This temperature was maintained for 2 hours, after which the supply of heat was shut off. The load was not removed from the brick until the furnace had cooled down.

6. Slagging Test.[1]—Upon the smooth side of the bricks selected for the test 2 rings were placed so that their centers did not approach closer than 2 inches from the sides of the brick, or their centers lie closer than 4$^1/_2$ inches apart.

The rings were 2$^1/_2$ inches, inside diameter, $^1/_2$ inch deep, and had walls $^1/_2$ inch thick. They were made from the same material as the brick under test and were cemented on with carborundum cement.

The slag[2] used was mixed from chemically pure materials, melted in a plumbago crucible, and crushed to pass a 48 mesh screen. The analysis of the slag showed it to have the following composition:

SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	MnO	Na_2O	Total
23.26	16.27	17.35	25.00	8.54	3.90	6.20	100.52

This conforms closely to slags encountered in metallurgical work.[3] Thirty-five grams of the powdered slag were put in the ring and equally distributed. The brick was then placed upon a level hearth, cold, and the temperature gradually raised to 1350°C, 5 hours being allowed to bring the brick to the above temperature. This temperature was maintained for 2 hours.

When cold the bricks were broken so that one of the broken surfaces bisected the center of the rings. The distance which the slag had penetrated or discolored the bricks was measured and the area calculated by Simpson's,[4] or the trapezoidal rule.

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[1] Taken from the *American Society for Testing Materials,* **19,** 586.

[2] This is approximately the slag recommended by the A.S.T.M.

[3] According to A.S.T.M. the brick should be placed on the cold level hearth of a furnace and allowed not less than 5 hours to attain 1350°C. The thirty-five grams of slag are then introduced. Due to the construction of our furnace it would be very difficult to introduce the slag at 1350°C.

[4] Planimeter recommended.

7. Spalling Test.—The spalling tests were made as follows: A brick free from cracks was dried for at least 5 hours at 110°C. This brick was placed in the furnace which was heated to 1350°C so that one-half of it was exposed to the flame, one-fourth imbedded in the cover of the furnace, and one-fourth projected clear through. The brick was heated for 30 minutes, removed and the half-heated portion was plunged into 6 kg. of water whose initial temperature was 20°C and allowed to remain 3 minutes. The brick was then removed from the water and all loose pieces were broken off. After cooling in the air for three minutes the brick was replaced in the furnace. The pieces broken off after each cooling were weighed. This heating and cooling of the brick was repeated 10 times unless the brick failed before.

The furnace used in this test was the one with the beam removed described above. Brick work was built up to within one-half brick length of the top of the furnace. Two bricks were tested at a time by placing them on top of this column of brick, the free ends passing through the cover. Gases were prevented from rising between the bricks and the cover by means of small briquettes set in to fill the cracks.

IV. Development of a Formula by Which We May Compare Carborundum Bricks with Clay Bricks

Before subjecting any bricks to these tests it was thought advisable to see if a relation could not be found between the results obtained from the test bricks and the length of time similar bricks would last in the furnace. This relation should be expressed by some numerical value and could then easily be compared with other brick whose numerical value had been determined. This numerical value should be based upon results obtained from standard tests, thus making it possible to calculate the value from previous work. It should take into consideration the various agents of destruction which the brick must be called upon to resist, and should be applicable to any brick for any work.

In consideration of this problem it is natural to look upon the life of a brick as a function of the various destructive agents. If we accept this analogy as holding true, at least formally so, then the life of a brick is proportional to the sum of all the destructive forces and our first step will be to define some of the terms which will be used throughout this discussion.

The predicted life of a brick may be defined as that number which represents the total number of days the brick may be expected to give useful service.

The destructive action may be defined as the sums of all the destructive forces when each force is weighted according to the results of the test.

$$\text{The rate of destruction} = \frac{\text{destructive action}}{\Delta T} = \frac{\Delta S}{\Delta T}$$

The relation between the predicted life of a brick and the destructive action may best be shown by the expressions:

$$\text{destructive action} = \frac{K}{\text{predicted life of a brick}},$$

$$\text{or, predicted life of a brick} = \frac{K}{\text{destructive action}}.$$

This expression states that the life of a brick is inversely proportional to the destructive action, and that when the destructive action is small the life of a brick becomes great, and vice versa.

Let us consider a brick which has been subjected to some one destructive agent, say slagging, and the length of time it has resisted this action before failing be known. Let us represent the result from the slagging test on this brick by Δp. Then Δp is a measure of its resistance to destruction by slagging, and its rate of destruction over the test period may be expressed by the secant $\Delta p/\Delta t$, where the curve $t=f(p)$ represents the relation between slag penetration and time. The actual shape of this curve is not known or required, because we are only interested in the secant $\Delta p/\Delta t$ which is obtained from the test brick.

If now the secant $\Delta p'/\Delta t$ for some unknown brick is obtained we have, since destructive action $= \Delta p$, the life L'_p of the unknown equal to $\dfrac{K}{x(\Delta p')}$.

By a similar process of reasoning we may obtain similar expressions for L_c and L_s where

$$L_c = K_2/x_2(\Delta c) \text{ and } L_s = K_3/x_3(\Delta s)$$

if L_c = the predicted life when the brick is subjected to pressure alone, and L_s = the predicted life when the brick is subjected to changes in temperature alone.

If now we have two destructive forces acting, say slagging and compression, the total destructive action may be given approximately by the expression $y_1(\Delta s)+y_2(\Delta c)$ and for any number of such agents we have approximately $z_1(\Delta s)+z_2(\Delta c)+z_3(\Delta p) \ldots\ldots$

By definition the life becomes:

$$L = \frac{Kn}{z_1(\Delta s) + z_2(\Delta c) + z_3(\Delta p) \ldots\ldots}$$

where z_1, z_2, z_3, represents the relative importance of the destructive action for any particular use to which the bricks are to be put, and will be referred to as the weight assigned to these destructive forces.

Let the quantity Δc represent the results from the load test, Δp the results from the slagging test, and Δs the results from the spalling test. It is perfectly obvious that if a given brick were subjected to the above 3 destructive agents it would outlast a similar brick subjected to a fourth destructive agent such as abrasion. Again, if this same brick were subjected to one of the above destructive agents it would last longer than when all 3 were acting. In this way it can be easily seen that the greater the number of destructive agents the shorter will be the life of the brick. Hence, in selecting a brick for any one job we must consider the destructive agents which are called into play. As an example, bricks which are used for lining flues, have a temperature which is fairly constant and the spalling action may be neglected. The load upon the brick is small but the slagging and abrasive action is appreciable. In this case the predicted life of a brick is equal to $k/(z_1(\Delta p)+z_2(\Delta a))$ where Δa represents the results from the abrasion test.

In the case of a blast furnace where we have a load acting, fluctuations in temperature, slagging, and abrasion, the average predicted life of the brick is equal to

$$\frac{Km}{z_1(\Delta c) + z_2(\Delta s) + z_3(\Delta p) + z_4(\Delta a)}.$$

Having obtained Δc, Δs, and Δp, from the test, it is necessary to put these values into a suitable form to substitute in the equation. We shall follow 2 rules in this calculation, first, that a brick which fails completely is 100% imperfect and one which stands up absolutely is 0% imperfect; second, a brick which fails partly during any period of a test is better than one which fails completely.

8. Calculations of Δ_c, Δ_p and Δ_s.—If a brick were completely crushed or failed during the load test we would record it as a 100% imperfect brick. If out of 3 bricks tested 3 should fail then this would be recorded as a grade of brick 100% imperfect as far as the load test was concerned. If two should fail we would multiply the per cent linear compressions of the brick which did not fail by $\frac{3}{3-2} = 3$ so that Δc becomes $\frac{L \times T}{T - F}$. L = average per cent linear compression of the brick which did not fail, T = number of bricks tested, and F = number of bricks which failed.

To calculate Δp we shall assume that when the slag has penetrated the depth of the brick straight down from the inner sides of the ring the brick has completely failed. If on the other hand no penetration has taken place the brick has failed 0 per cent. Hence to calculate the above quantity we need only find the percentage of area destroyed. The expression for this is $p = \Delta A/A \times 100$. Where A = depth of brick × diameter of ring = 36 sq. cm. in these test brick, A = area destroyed by slag.

To calculate Δs we proceed as follows: Let the maximum number of coolings to which we intend to subject the brick be designated C. Then a brick may be considered to have failed when it has lost $\frac{100\%}{C}$ of its initial weight. Thus if C is taken as 5 we shall assume the brick has failed when it has lost $\frac{100}{5}$ = 20% of its weight. If we select 10 coolings then the brick is considered to have failed when it has lost 10% of its weight. If we assume the brick has failed 100% when it loses $\frac{100\%}{C}$ of its weight after the first cooling we will have the expression

$$100 = \frac{100}{C} \times (C-T) + \frac{10}{C} \times W,$$

where W = loss in weight = C at complete failure, and if we assume that the brick has failed 0% when it has lost none of its initial weight after C coolings, we have

$$0 = \frac{100}{C} \times (C-C) + \frac{10}{C} \times W$$

and the expression

$$S = \frac{100}{C} \times (C-T) + \frac{10}{C} \times W$$

shows the percentage failure. The weights z_1 z_2 z_3 to be assigned Δc, Δp and Δs may be most easily determined after the results from the test brick have been given.

V. Fabrication of Carborundum Brick

Whenever sufficient clay is added to carborundum so as to fill the voids and surround each particle with clay there will be no trouble experienced in pugging or moulding the mixture. However, when these conditions are not fulfilled trouble begins and continues to increase as the percentage of clay is diminished. In the case of carborundum and Grand View Fire Clay it is almost impossible to pug a mixture containing 5% less clay than the theoretical requirement, but with certain plastic fire clays mixtures containing considerable less than the theoretical amounts may be successfully pugged. The reasons for this are obvious.

The bricks tested and given in Table I were mixed, rotted, and so forth, together so as to insure the same treatment throughout their fabrication. Due to the high percentage of carborundum bricks 15 and 16 had to be built up while the others were moulded by an expert brick maker, and it is reasonably certain that they were all wedged alike.

Considerable trouble was experienced with bricks 15 and 16 by failing along the cleavage planes, and whenever a failure was due to these cleavage planes the result was discarded. This action was justified because there is a difference between a brick failing by a break down of the material itself, and one failing by improper fabrication. To eliminate these cleavage planes great pressures are required.

The different bricks which were subjected to these tests are given in Table I. The test of deformation at high temperature was conducted upon bricks 5–8 inclusive, 21, 22, 24, 25 and 26. The slagging test was conducted upon bricks 1–16 inclusive, 26 and 27. The spalling test was conducted upon bricks 1, 5–9 inclusive, 13, 17–22 inclusive, 24–26 inclusive. In Table II, are given the various screen analyses of the carborundum used in the different mixtures. The second column of Table I designates which screen analysis was used.

TABLE I—MIXTURES OF CARBORUNDUM CLAY

No.	No. of screen analysis	PERCENTAGE Carborundum	Clay	Clay used
1	1	50	50	G. V. Fire Clay
2		60	40	
3		70	30	
4		80	20	
5	2	50	50	G. V. Fire Clay
6		60	40	
7		70	30	
8		80	20	
9	3	50	50	G. V. Fire Clay
10		60	40	
11		70	30	
12		80	20	
13	4	50	50	G. V. Fire Clay
14		60	40	
15		70	30	
16		80	20	
17	2	50	50	Illinois Kaolin Non-Selected
18		60	40	
19		70	30	
20		80	20	
21	2	50	50	Washed G. V. Fire Clay
22	2	65	35	Non-Selected 17.5% G. Clay 17.5%
23	5	45	55	G. V. Fire Clay
24	Old Bricks 70% Carb.	Crushed Bricks Coated with slag		Washed G. V. Fire Clay

	30% Clay			
	2	60	40	
25	Old Bricks	Crushed Bricks		Washed G. V. Fire Clay
	70% Carb.	with slag removed		
26	30% Clay	60	40	G. V. Fire Clay
		0	100	
27	2	70	30	Washed G. V. Fire Clay

TABLE II—SCREEN ANALYSIS

No. of screen analysis	Mesh	Per cent weight	No. of screen analysis	Mesh	Per cent weight
1	On 14	.18	2	On 14	.12
	20	2.54		20	3.22
	28	32.52		28	29.19
	35	25.19		35	21.19
	48	15.51		48	12.59
	65	14.23		65	12.34
	100	7.12		100	7.06
	120	2.54		150	6.17
		99.78		200	2.68
				thru 200	4.98
					99.54
3	On 14	.32	4	On 150	43.3
	20	6.66		200	22.2
	28	23.80		thru 200	34.5
	35	14.42			100.0
	48	8.29	5	On 14	.08
	65	8.03		20	2.53
	100	4.64		28	17.30
	150	14.44		35	16.82
	200	7.53		48	13.84
	thru 200	11.72		65	16.00
		99.85		100	20.00
				150	10.77
				200	2.94
					101.28

VI. Results Obtained from Test Brick

9. Decrease in Resistance to Deformation at High Temperatures.—The decrease in resistance to deformation at high temperatures are given in Table III. From this table it is perfectly obvious that the greater the percentage of carborundum the greater is the resistance to this deformation. The failure of bricks

7 and 8 was due to spalling along the cleavage planes. In the 3 failures recorded the bricks split in two lengthwise through the center. These failures as mentioned before were due to the method employed in making the bricks, and could probably be eliminated by making them under great pressure.

TABLE III

No.	Per cent linear compression	No.	Per cent linear compression
5	1.6	21	1.92
5	3.0	21	1.75
5	2.2	22	2.42
6	1.00	22	2.65
6	1.51	22	2.44
6	2.01	24	failed
7	failed	24	7.26
7	failed	24	failed
7	.96	25	failed
8	.86	25	failed
8	failed	26	7.6
21	1.8	26	10.1
		26	12.3

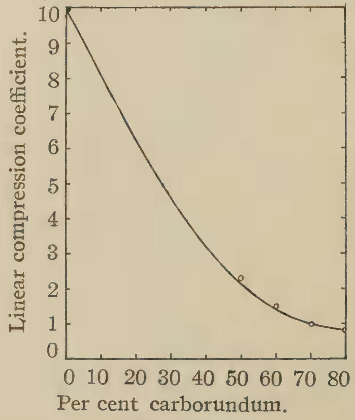

FIG. 3.

The results of the deformation test on bricks 5–8 inclusive, and 26 are shown graphically in Fig. 3. This curve represents the resistance offered to the linear compression of the bricks and may be expressed in terms of the per cent carborundum as follows:

$R = 0.03775\,(80-C)^2+.86.$

R = The effect of linear compression.

$\frac{K'}{R}$ = life.

C = per cent carborundum.

From this curve it is evident that where great loads are to be sustained at high temperatures a high percentage of carborundum is desirable. Brick 21 which contains washed Grand View Fire Clay stood up in excellent shape. Brick

22 is also an excellent brick, its appearance after the test being much better than any other brick tested.

10. Slagging.—Table IV shows the effect of slagging upon different mixtures of carborundum and clay, together with different sizes of carborundum. There seems to be no general law followed except that the mixtures high in clay stand up a trifle better than those containing a great deal of carborundum.

TABLE IV—SLAGGING TEST ON MIXTURES OF CARBORUNDUM AND CLAY BRICKS

No. of brick tested	Brick no.	Average area penetration in square cm.
3	1	2.04
3	2	1.51
3	3	3.33
3	4	3.44
3	5	2.04
3	6	3.80
3	7	2.10
3	8	2.74
3	9	1.23
3	10	2.32
3	11	2.08
3	12	2.82
3	13	2.10
3	14	2.11
3	15	1.75
3	16	2.46
3	26	2.00
3	27	1.53

The results from the slagging test on bricks 5–8 inclusive, and 26 are shown graphically in Fig. 4. The penetrations were small and difficult to measure and for this reason there is considerable uncertainty about each point. It is very improbable that the law followed is indicated by the jagged line and for this reason the dotted line B was selected. This line is of the first degree and probably represents the results as close as they can be determined with the present method of making these measurements. These results were so different from what had been expected that it was thought advisable to make a further study of the action of slags upon carborundum. Only a brief summary will be considered here.

It was found that carborundum would resist the action of most slags better under reducing than oxidizing conditions. That slags high in lead would quickly oxidize the carbon and unite with the silicon, in fact, when 25 grams of carborundum was mixed with 50 grams of lead oxide and heated at 1350°C for 30 minutes a 12-gram lead button was obtained in the crucible. Slags high in iron and silica also destroyed carborundum. On the other hand, slags high in silica and low in lead, iron and lime had practically no effect upon the carborundum.

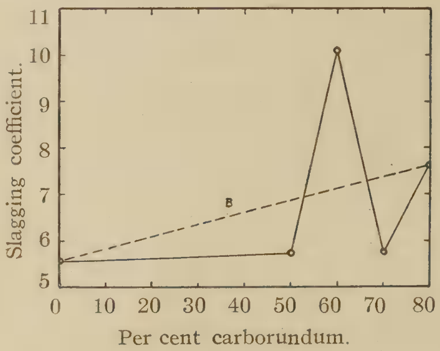

FIG. 4.

11. Spalling.—The results from the spalling test are given in Table V. In Fig. 5 the results for the various mixtures of carborundum (No. 2 screen analysis) and Grand View Fire Clay are shown graphically and also brick 26.

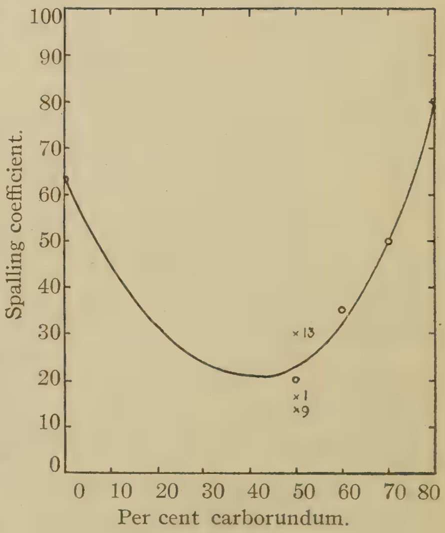

FIG. 5.

Here an attempt was made to test bricks which were alike in every respect except for the different percentages of carborundum used in the mixtures. It is obvious from this curve that up to a certain point the additions of small percentages of carborundum greatly decreases the rate of spalling. As more carborundum is added the change is less great and at last a point is reached where the addition of more carborundum

TABLE V—EFFECTS OF QUENCHING

No.	Temp. of fur. °C	Number of quenching	No effect	Small cracks	Large cracks	Failed
1	1350	8	1–2–3–4–5–6	. . . .	7	8
1	1350	10	1–2	3–4–5–6–7–8–9	. . . .	10
1	1350	10	1	2–3–4–5–6–7–8–9	. . . .	10
5	1350	9	1–2	3–4–5–6	7–8	9
5	1350	10	1–2	3–4–5–6–7	8–9	10
5	1350	8	1–2	3–4–5–6	7	8
6	1350	9	1–2	3–4–5–6–7	8	9
6	1350	6	. . . .	1–2–3–4	5	6
7	1350	6	. . . .	1–2–3–4	5	6
7	1350	3	1	. . . .	2	3
7	1350	9	. . . .	1–2–3–4–5–6	7–8	9
8	1350	3	. . . .	1	2	3
8	1350	1	. . . .	. . . .	. . . .	1
8	1350	5	. . . .	1–2	3–4	5
9	1350	7	. . . .	1	2–3–4–5–6	7
9	1350	10	. . . .	1–2–3–4–5–6–7–8–10	. . . .	. .
9	1350	10	. . . .	1–2–3–4–5–6–7–8–10	. . . .	. .
13	1350	9	. . . .	1–2–3–4–5	6–7–8	9
13	1350	9	. . . .	1–2	3–4–5–6–7–8	9
13	1350	6	. . . .	1–2–3–4–5	. . . .	6
17	1350	5	. . . .	1–2	3–4	5
18	1350	10	1–2	3–4–5–6	7–8–9	10
19	1350	9	1–2–3–4–5	6–7	8	9
20	1350	10	1–2–3–4–5–6	7–8–9–10	. . . .	. .
21	1350	10	1	2–3	4–5–6–7–10	. .
21	1350	10	1	2–3	4–5–6–7–10	. .
22	1350	10	1–2–3–4	5–6–7–8–9–10	. . . .	. .
22	1350	10	1–2–3–4	5–6–7–8–9–10	. . . .	. .
22	1350	10	1–2–3–4	5–6–7–8–9–10	. . . .	. .
24	1350	10	1–2–3	4–5–6	7–8–9–10	. .
24	1350	10	1–2–3	4–5–6	7–8–9–10	. .
25	1350	8	1–2	3–4–5–6–7	. . . .	8
25	1350	10	1–2–3	4–5–6–7	8–9	10
26	1350	4	1	2	3	4
26	1350	6	. . . .	. . . .	1–2–3–4–5	6
26	1350	4	. . . .	. . . .	1–2–3	4

becomes a detriment and increases the spalling. This curve represents the resistance offered to the spalling action of the various bricks and is expressed by the equation:

$$R = 5(.025\,C)^4 + \frac{80 - C}{1.35 + .03 \times C}$$

where R = effect of spalling action, K = a constant, $C = \%$ carborundum.

The carborundum from the No. 2 screen analysis represents the regular proportion of sizes received and is the only one on which a spalling test was made upon a series of different mixtures. The spalling tests were also run upon bricks 1, 9, 13 and are shown in Fig. 5. From this test it is seen that the material should contain a little more fines so as to conform to screen analysis No. 3. (See point 9.) Point 1 represents the coarse material which apparently resists spalling better than brick 13 which contains all the fine material. (Screen analysis No. 4.) Referring to bricks 17–20 inclusive, we see that in the case of Illinois kaolin 50% carborundum is not sufficient while 60, 70 and 80% is much better. Brick 20 which contains 80% carborundum stood up best in these tests.

Only one brick of the various mixtures of Illinois kaolin and carborundum were tested, and for this reason very little weight can be given to any particular results.

Having tested our brick and obtained Δc, Δp and Δs we are now ready to determine z_1, z_2 and z_3. If the life of a carborundum brick is greater than that of a clay brick it must be due to a difference in their properties. Thus if the clay and carborundum bricks each resist slagging equally well we could not say that the superiority of the carborundum brick was due to its resistance to slagging. But on the other hand, if the difference between their linear compressions was great, then this must be a very important factor in increasing the life, and the weight assigned to linear compression should be a function of the ratio of compression between a carborundum and a clay brick. Since the linear compression of the carborundum brick varies as the second power of the per cent carborundum present, it is only reasonable to weight it as the square of the ratio between a clay brick and a clay carborundum brick. In the same manner the weight assigned to the spalling tests was taken as the ratio of the spalling tests raised to the fourth power. The weight assigned to the slagging test was taken as the ratio of the two to the first power.

Having determined the method of weighting these different results the next step was to decide which mixture of carborundum should be used in this ratio. The most logical one to use is that one which will bring out most strongly the properties which characterize a carborundum brick. For this reason a brick containing the proper proportion of clay from a theoretical standpoint was used. According to the void test it was found that 68% carborundum was required. To determine the action of a brick containing 68% carborundum we shall refer to Figs. 3, 4 and 5.

Fig. 3. We have $\Delta c = 1.02$ Linear compression for brick containing 68% carborundum.
$\Delta c = 10$ Linear compression for brick containing 0% carborundum.
Fig. 4. We have $\Delta p = 7.3$ Slagging test for brick containing 68% carborundum.
$\Delta p = 5.56$ Slagging test for brick containing 0% carborundum.
Fig. 5. We have $\Delta s = 45$ Spalling test for brick containing 68% carborundum.
$\Delta s = 63$ Spalling test for brick containing 0% carborundum.

Forming the above ratios we have:

$$\left(\frac{63}{45}\right)^4 = 3.84$$

$$\left(\frac{10}{1.02}\right)^2 = 96$$

$$\frac{5.56}{7.3} = .762$$

Reducing these to whole numbers by dividing each factor by the smallest one (0.762) and taking the closest to 5 which is as close as the results warrant, we have: Weight for Spalling Test, 5 or 5, Linear Compression Test, 126 or 125, Slagging Test, 1 or 1, so that our formula becomes for these three destructive agents,

$$L = \frac{K'}{125.\,\Delta s + 5.\,\Delta c + \Delta p}$$

Having now determined numerical values for all of our unknowns we are ready to calculate the predicted life of the carborundum bricks. According to the operating report the life of the clay bricks in this furnace was 151 days. Referring to Figs. 3, 4 and 5, we have:

$$\text{Life of clay brick} = \frac{K'}{25 \times 10 + 5 \times 63 + 5.6} = \frac{237220}{1571} = 151 \text{ days}$$

and for the carborundum bricks we have

$$\text{Life } \frac{50}{50} \text{ brick } = \frac{237220}{125 \times 2.3 + 5 \times 20 + 7} = 600 \text{ days.}$$

$$\text{Life } \frac{60}{40} \text{ brick } = \frac{237220}{125 \times 1.52 + 5 \times 35 + 7} = 640 \text{ days.}$$

$$\text{Life } \frac{70}{30} \text{ brick } = \frac{237220}{125 \times 0.96 + 5 \times 50 + 7} = 629 \text{ days.}$$

$$\text{Life } \frac{80}{20} \text{ brick } = \frac{237220}{125 \times 0.86 + 5 \times 80 + 8} = 459 \text{ days.}$$

Curve (*B*) Fig. 6 shows these values plotted. Curve (*A*) shows the actual life of these bricks in Furnace No. 25. According to the theoretical curve the increase in life is very small after 50% carborundum has been added and decreases very rapidly after the addition of 65%. In curve (*A*), the bricks containing 60% carborundum show a much greater life than any other mix, but it

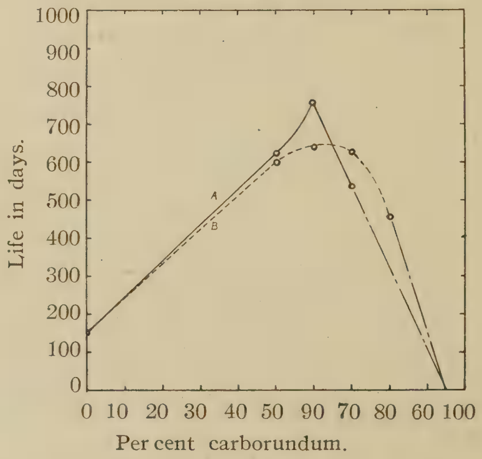

Fig. 6.

A.—Curve showing life of bricks in furnace #25.
B.—Curve showing life of bricks as calculated.

seems very improbable that this great life will be maintained over a longer period. It may be well to note here that the mixtures used in the furnace were taken from curve (*B*) and that curve (*A*) is really a check on the information given in this report.

As mentioned previously the abrasive action was not considered in calculating the life of these brick. If it had it is apparent that the calculated values would have been greater, thus making the two curves practically identical.

When this expression was developed and the predicted life calculated for the various mixtures it was hardly expected that the true values would check out as closely as they did. It was hoped however that the curve would show the relative value of each brick, so that an approximation to the most suitable mixture could be obtained under operating conditions. It is apparent that these expectations were realized. Brick No. 9 stood up best in the spalling test on mixtures of carborundum and Grand View Fire Clay, and while its screen analysis does not exactly conform to that given in problem No. 4 of this paper it approaches nearer to it than the other three.

VII. Theoretical Explanation for the Physical Properties of Carborundum Bricks

12. The results from the spalling test indicate that the addition of a certain amount of carborundum reduces the spalling, while if too much is added the spalling is increased. This may be accounted for as follows: Let us pass two parallel planes, *AB* and *CD* (see Fig. 7), through a refractory material and let the distance between these two planes be Δs. Let us also assume that heat is flowing from plane *AB* to the plane *CD*. Then the temperature of the face *AB* must be greater than *CD* by Δt. If we denote the coefficient of expansion of the mixture by e, then the face *AB*, is longer than *CD* by the amount $e \times \Delta t$ and the increased length per unit is $e \times \frac{\Delta t}{\Delta s} = e$ multiplied by the (temperature gradient).

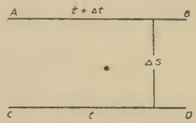

Fig. 7.

If we multiply this by some constant K we may change this increase in length to pounds pressure per unit area set up in the clay. When the strain set up is less than the tensile strength of the mixture we have no cracking, when greater than the tensile strength we have cracking. This may be expressed more concisely in the form

$$K.e.\frac{\Delta t}{\Delta s} - T = Y$$

when Y is $-$ we have no cracking; when Y is $+$ we have cracking. (The coefficient of expansion e, the temperature gradient $\frac{\Delta t}{\Delta s}$, and the tensile strength T) are all functions of the quantity of carborundum in the mixture, the physical characteristics of the clay, the wedging of the mixture in fabricating the brick, and the temperature under which the refractory is working.

Fig. 1 shows the tensile strength of different mixtures of carborundum and Grand View Fire Clay. It will be noted here that the spalling is least when the tensile strength is nearly a maximum. In case of Illinois kaolin[1] the tensile strength is much greater than that of Grand View Fire Clay, and the maximum tensile strength is obtained with a higher percentage of carborundum.

We know that as the ratio of carborundum to clay is increased $e \times \frac{\Delta t}{\Delta s}$ is diminished. In the case of Illinois kaolin T is a maximum when the percentage of carborundum is high, so that we would predict that a higher percentage of carborundum is required than with Grand View Fire Clay. This was borne out by Brick 20 in the test.

From the equation $Ke.\frac{\Delta t}{\Delta s} - T = Y$, we may draw the following conclusions: (*a*) The coefficient of expansion of the mixture should be made as small as possible. With most clays this can be done by increasing the percentage of carborundum; (*b*) The temperature gradient $\frac{\Delta t}{\Delta s}$ is a function of the percentage of carborundum present, and decreases as the percentage of carborundum is increased; (*c*) K is a constant independent of e or $\frac{\Delta t}{\Delta s}$. For this reason it is desirable to make the product $e.\frac{\Delta t}{\Delta s}$ as small as possible and this is done by making the percentage of carborundum great; (*d*) T, however increases until a certain amount of carborundum has been added and then decreases very rapidly. The mixture of carborundum and clay which will withstand the changes in temperature to the best advantage is that which will make Y a minimum and is shown graphically in Fig. 5 for Grand View Fire Clay.

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[1] The curve for Illinois kaolin is not shown.

From these conclusions it is quite evident that the resistance offered to spalling by any mixture of clay and carborundum depends upon its coefficient of expansion, thermal conductivity and tensile strength, and that if two clays have the same coefficient of expansion, the same thermal conductivity, and are mixed with equal percentages of carborundum, the one with the greater tensile strength will spall the least. Other comparisons are obvious. From this it is evident that carborundum decreases the spalling action by increasing the tensile strength, increasing the thermal conductivity and decreasing the coefficient of expansion of the mixture.

We are now ready to consider why it is so important to have suitable mixtures of various sizes. As an exaggerated case let us consider a mixture of very coarse material containing very little fines (Fig. 8) in which the voids are filled with clay. Let a = the coefficient of expansion of the carborundum; b = the coefficient of expansion of the clay. L_0 = distance between two arbitrary planes P and Q. $\Delta L_0 = \Sigma\, e$ where e_i represents the width of the layers of clay separating each carborundum particle along the line EF. $\Delta C_0 = \Sigma\, s$ where s_i represents the width of any particle of carborundum along the line GH. When $t=0$ we have

$$(L_0 - \Delta L_0)(1+at_0) + \Delta L_0(1+bt_0) - (L_0 - \Delta c_0)(1+bt_0) = 0$$
$$\text{or } (L_0 - \Delta L_0 - \Delta C_0)(a-b)t_0 = 0$$

and there is no strain between the two surfaces EF and GH. If now the temperature is raised to t_1, we have

$$(L_0 - \Delta L_0 - \Delta C_0)(a-b)t_1 = z \neq 0 \text{ if } a \neq b$$

so that a strain will be set up between the two planes which equals $\frac{kz}{\Delta s}$ pounds per unit area. When $\frac{kz}{\Delta s} > T$ the brick will crack. At high temperatures the clay becomes more or less plastic and the particles will so adjust themselves that the strain is less than that expressed by the formula. To adjust themselves the particles along the line *EF* must move relative to those along *GH* so that we have a sliding action going on within the brick. This movement of the particles is as undesirable as the strain.

If the voids in Fig. 8 are filled with carborundum the difference between the 2 terms in the above expression becomes less for any temperature *t*, and if the sizes of the particles of carborundum are so selected that they fill the voids the above expression will become very nearly equal to zero, and will equal zero when *EF* and *GH* have the same amount of clay and carborundum.

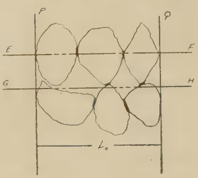

Fig. 8.

The quantity of heat transmitted from the surface *FH* to the surface *GH* will be greatest when the voids are filled with carborundum, so that from a theoretical standpoint the best results are obtained when the sizes are mixed so as to produce a minimum of voids. These conclusions have been borne out by the test brick and mentioned elsewhere.

From a consideration of Fig. 3 it is quite evident that the linear compression varies as the second power of the percentage of carborundum present. This may be readily explained as follows: Let us consider a clay brick in which both the grog and binding material have approximately the same softening point. If now a load is applied to the brick linear compression will take place. Both the particles of clay and grog will flatten out in proportion to the percentage of compression. Let us now replace the grog with carborundum. As the temperature is raised the clay will soften as before, but the carborundum remains rigid. In order for linear compression to take place the clay must now spread out around the particles of carborundum. This causes a much greater movement of the clay for a given compression of the brick and of course the rate of compression must be much slower. Since the movement of the clay around the carborundum is in a plane we should expect it to vary as a function of the second degree which is borne out by the curve. Much trouble was experienced in testing the bricks containing considerable carborundum. This was due to the fact that the bonding strength was so low that the horizontal strains set up in the bricks caused it to rupture. Most of the trouble found in the 80–20 bricks would have been eliminated if better facilities could be had for fabricating them. It simply points out the fact, however, that the addition of too much carborundum makes difficulties which can not be overcome.

The results from the slagging test do not show a great deal of variation between clay bricks and clay carborundum bricks. Not only was this borne out by the test bricks but it has been found true in practice. In fact, in many cases the clay bricks have proven superior to the carborundum bricks from the standpoint of slagging.

Unless the slagging action is extremely great, however, carborundum is an excellent body for bricks where these physical destructive agents are severe. The fact that they resist abrasion, spalling, and deformation are the main reasons for their increased life in ordinary furnace work.

VIII. General Conclusions

(*a*) The various sizes of carborundum should be so proportioned that we have a maximum amount of coarse material with a minimum of fines, but sufficient fines must be added to fill the voids of the preceding coarser sizes. To realize this practically the dimensions of the finer sizes must approach zero as the voids become smaller and smaller. Therefore these conditions can only be approximately approached.

(*b*) The percentage of clay which should be added to the carborundum to fill the voids will depend upon the ratio of the sizes of the carborundum particles.

(*c*) Other things being equal the tensile strength of any mixture of carborundum and clay is proportional to the bonding power of the clay. When different percentages of carborundum and clay are mixed together the tensile strength increases rapidly at first, then remains practically constant, and finally decreases very rapidly. The proper percentage of carborundum to use in any mixture to obtain the maximum tensile strength will depend upon the physical characteristics of the clay.

(*d*) When sufficient clay is added to carborundum to fill the voids and surround each particle with carborundum there will be no trouble in pugging or moulding the mixture. When these conditions are not fulfilled trouble begins and increases as the percentage of clay is diminished.

(*e*) The linear compression varies as the second power of the percentage of carborundum present, so that where bricks are to be subjected to great pressures the percentage of carborundum should be as high as possible.

(*f*) Carborundum will resist the action of most slags better under reducing than oxidizing conditions. It will not resist slags high in iron, lead or lime, but will resist those high in silica.

(*g*) The length of time a brick will resist spalling depends upon the percentage of carborundum in the brick, the tensile strength, coefficient of expansion, and thermal conductivity of the clay.

(*h*) Each bond clay presents a different problem and the proportions to use can only be determined by trial.

(*i*) The formula shows that a good bond clay should have the following properties: (1) High tensile strength, (2) high softening point, (3) low coefficient of expansion, (4) high thermal conductivity, and that a good body should have (1) rigidity at high temperatures, (2) low coefficient of expansion, (3) high thermal conductivity.

(*j*) And finally, if the refractories are to be used where the physical destructive forces are great (spalling, compression, abrasion, etc.) and the chemical forces small, carborundum will make an excellent grog. If the slags which come in contact with the refractories are high in silica carborundum may still be used. If the slags are high in iron, lead and lime and occur in great amounts, then carborundum should not be used.

THE TESTING OF SILICA BRICK

By K. H. Endell[1]

ABSTRACT

The Steger Load Test Apparatus.—Pressure was applied, in a granular-carbon resistance furnace, to the small test cylinders by means of a hollow carborundum rod. The temperature was read with an optical pyrometer sighted through this hollow pressure rod. The volume changes were indicated by a pointer and scale and recorded by means of a rotating drum. (See Fig. 1.)

Estimation of Quartz and Cristobalite in the Finished Brick.—The areas occupied by each type of crystal on the photomicrograph were determined with the aid of a transparent cross-section grating.

Suggested Specifications for A1 Silica Brick.—True specific gravity not greater than 2.38; not more than 2% permanent linear expansion after heating to 1600°C in one and one-half hours, and holding at that temperature for one-half hour; the amount of quartz (and silicates) as determined by the grating method applied to photomicrograph should not exceed 15%.

Silica brick are assuming a position of ever-increasing importance among refractory materials. The greater value of silica brick as compared with fire-clay brick in resistance to high temperatures under load conditions and as regards their heat conductance is generally admitted. Silica brick are being used in ever-increasing numbers not only in steel furnaces, but also in coke ovens and for segments in the making of gas retorts.

Consonant with their great economic value for technical purposes, scientific investigations, during the last few years, have dealt with the determination of the properties of silica brick. Especially in the United States of America contributions of high value have been published on this subject, among others by Kenneth Seaver, J. Spotts McDowell, A. V. Bleininger, D. W. Ross, H. Insley and A. Klein, R. J. Montgomery and L. R. Office, and F. A. Harvey and E. N. McGee.

But in other countries also many experimental tests have been made and a great deal of research work on silica brick has been going on. Proper mixing of the raw materials and a sufficiently long firing period are essential to the utilizability of silica brick. In Germany, where the conditions are best know to me, quite a different class of quartzite is used than in America. Some brief comparative tests made by me with German and American quartzites were published recently in the *Journal*.[1] German tertiary quartzites, so-called erratic-block quartzites, mostly show under the microscope, in a finely crystallized basal cement, peripherally corroded quartz crystals, which increase greatly in volume in the "first fire" up to Seger Cone 14. The American silurian and devonian quartzites on their part show in thin sections under the microscope, closely packed grains of quartz, which increase far less in volume during the first stage of heating. But as a maximum of transformation in the initial stage of burning is a consummation highly to be desired, brick of American quartzite demand treatment either at considerably higher temperatures or for a much longer period than the German erratic-block quartzite. The utilization of the more favorable tertiary quartzites of Germany, therefore gives, as compared with American quartzites, a saving of coal.

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[1] Received February 2, 1922.

A useful schedule of silica brick tests in the laboratory was drawn up in 1918 by R. J. Montgomery and L. R. Office (as well as other speakers who joined in the discussion) and in 1921 by F. A. Harvey and E. N. McGee. For a period of ten years I have been engaged in examining the polymorphic structure of silica and in studying silica brick and that not only from a physico-chemical and mineralogical point of view, but also from the standpoint of the technique of practical testing.

Especially during the last few years I have tested a great number of silica brick in various connections. My researches were in the main confined to German silica brick, made partly by the factories of refractory materials attached to some great German steel works, supplying only the direct needs of those works, or by factories producing refractory materials for the market.

For purposes of comparison I submitted some American, English and Swedish silica brick to comparative tests.

My experiments covered the following properties:

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[1] *This Jour.*, **4,** 953(1921).

1. Specific gravity (determined volumetrically in the specific gravity bottle).
2. Determination of the temperature of rupture and the softening temperature under a load of 1 kg. per sq. cm. (equivalent to about 15 lbs. per sq. in.).
3. Linear expansion after repeated heating up to 1600 °C.
4. Microstructure, especially the proportion of quartz to cristobalite and tridymite.

The chemical analysis, the temperature of fusion expressed in Seger cones, the porosity, and the mechanical strength when cold, I do not consider of great importance.

The following details may be given concerning the special tests:

1. Specific Gravity.—All tests were made on *finely* powdered material in small pycnometers of 3 ccm. capacity using the boiling procedure. Volumetric tests by the boiling method have frequently led to too low results, thereby creating a false impression of a degree of transformation not warranted by the facts. In some 100 determinations, for the most part repeated several times, the difference in check determinations involved only the second decimal.

2. Determination of the Temperature of Rupture or the Softening Temperature under Load Conditions.—The tests were carried out partly with the lever-press previously described[1] and partly by the method of Dr. W. Steger, details of which are given in Fig. 1. By the first method the temperature of rupture was determined; by the second the softening temperature. The temperature measurement being quite different, a comparison of the absolute temperature range is not admissible.

To shorten the apparatus a one-armed lever was used. The load-bearing wagon is detachable so that it can be separated from the electric furnace, thus allowing the latter to be worked alone. The changes of volume of the fire brick cylinder are indicated on a scale. Recording is also possible by means of a rotating drum. The accurate measurement of the temperature is carried out with the aid of the Holborn-Kurlbaum pyrometer by means of the axis of the upper pressure rod through the center of which a perforation of 15 mm. in diameter passes. The apparatus that records the change in volume is constructed so as to admit a variation in the range of the pointer by changing the lever ratio. The load was 1 kg. per sq. cm. which is a very close approximation to practical conditions. Occasionally a load of 2 kgs. per sq. cm. was applied without any material alteration of the results. Hence it is possible to compare directly the results with those obtained in America, as these are mostly obtained with 1.7 kg. per sq. cm. which corresponds to 25 lbs. per sq. in. The test cylinders were uniformly made in the German Staatliches Materialprüfungsamt by cutting them, with a diamond drill cylinder 50 mm. in diameter and 50 mm. high, out of standard burnt brick ready for use. The ends of the cylinders were ground down and polished off smooth to the required height. I am quite aware, however, that this procedure results in destroying the outer integument of the brick which is of such great

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[1] K. Endell, *Stahl ü Eisen*, **41**, 6–9(1921); cf. *This Jour.*, **4**, 417(1921).

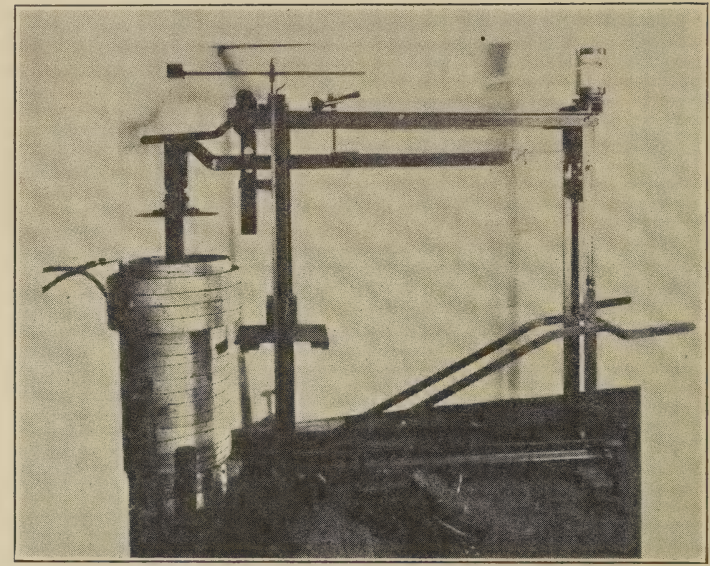

FIG. 1.—Dr. Steger's lever press with the carbon resistance furnace and the prism of the optical pyrometer.

value to all ceramic substances. To compensate for this, however, I had a uniform testing material. At times also cylinders of the same size were made in the laboratory in soft steel rings out of a mixture of silica raw material under a pressure of 300 kgs. per sq. cm. These were then burnt at a temperature of 1450 °C in the large porcelain furnace.

As the method worked out by the American Society for Testing Materials, by which after a fixed period of preheating a load of 1.7 kg. per sq. cm. acts on silica brick for a period of one and a half hours at 1500 °C or 4 hours at 1400 °C, produces no values that will bear comparison—for most bricks can stand so comparatively light a test—for a crucial test I adopted the determination of the temperature of rupture or softening under the given conditions with a load of 1 kg. per sq. cm. In this connection it should not be forgotten that the testing of a cylinder which is heated without any lateral support whatsoever takes place under far more severe conditions than when the silica brick in the wall is attacked only from one side by the direct influence of the heat. However, that may be, it is possible to establish comparative values. The determination of the temperature of rupture or softening under load conditions renders the determination of the SiO_2 content and the melting temperature expressed in Seger cones superfluous.

3. Determination of the Linear Expansion after Repeated Heating up to 1600 °C.—I quite agree with Mr. R. M. Howe[1] that it is of paramount importance to find out the degree of expansion after repeated firing. Heating as in the U. S. A. for 4 hours at a temperature of 1400 °C or for one and a half hours at 1500 °C seems to be insufficient. In steel furnaces silica brick are subjected to a temperature of at least 1600 °C and coke ovens too, under the forced firing of today are often operated at a temperature exceeding 1500°. To raise the temperature for testing up to 1600° seemed, therefore, the better way.

The experiment was conducted under the following conditions. The test cylinders (described in paragraph 3) of 50 mm. height and diameter were heated in granular carbon resistance furnaces for about one hour and a half up to 1600 °C. This temperature was kept constant for half an hour before cooling. Later on the electric muffle furnace pictured below was made use of. The carborundum muffle, embedded in granular carbon has a working space which admits of uniform heating and permits the use of standard bricks 6 x 12 x 25 cm. With the test cylinders it was possible to heat six at a time. With 120 volts and 100 amperes 1600°C was reached in an hour and a half. The linear expansion of the test cylinders heated up to 1600°C was measured with a sliding gauge after cooling. The corresponding determination of the specific gravities in most cases gave a result of 2.32-2.35. Thus the maximum expansion was almost reached. The examination of the microstructure in thin sections showed an increase in amount and an augmentation of grain size of cristobalite, which according to the experiments of the Geophysical Laboratory is the stable form of SiO_2 above 1470°C.

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[1] *This Jour.*, **1**, 348 (1918).

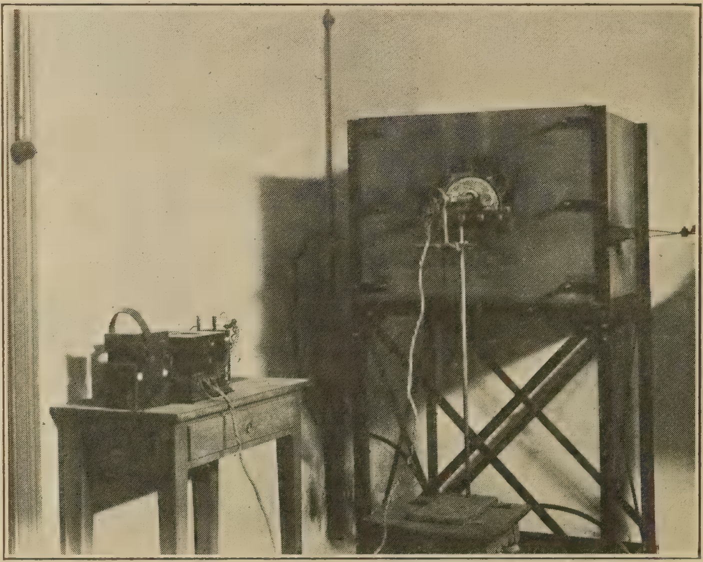

FIG. 2.—Electrically heated muffle furnace. Designed by the Didier Fire Brick Works of Stettin.

4. **Microstructure.**—All students of the behavior of silica brick have pointed out that the polymorphic condition of silica

at high temperatures is of prime importance. The important thing is to determine the relative amounts of quartz, cristobalite and tridymite as exactly as possible. For this reason C. H. Warren and J. Spotts McDowell, and H. Insley and A. A. Klein employed the method of determining the indices of refraction of the different minerals in the brick. This method is difficult to apply in a technical laboratory. The results of this method of investigation are controlled by the values of the specific gravity and the increases in volume on heating to 1600°C. For the technical testing of silica brick it seems sufficient, by means of a more simple method, to determine in the photomicrographs the amount of quartz and silicates the grains of which have a higher birefringence and a higher index of refraction.

This was done by placing a grating of transparent paper ruled in 1 millimetre squares on the photomicrographs which were usually magnified a hundred times. The squares containing quartz and silicate crystals were pricked with a needle and counted. The remainder is usually cristobalite, while tridymite in finished silica brick is represented in most cases by less than 5 per cent. The tridymite was estimated and the cristobalite determined by difference. I consider this method to be exact within about 2 per cent.

Conclusions

The following conclusions may be drawn from Tables I and II:

The correspondence between the values of true specific gravity, the subsequent increase in volume at 1600°C, and the amount of unaltered quartz in the completed brick are most striking. The lower the specific gravity and the smaller the subsequent increase in volume, the less quartz is to be seen in thin sections. A diagram of these conditions of correspondence as has been beautifully given by F. A. Harvey and E. N. McGee for linear expansion and specific gravity could not be made probably owing to the fact that the American test which involves heating for 4 hours up to 1400°C or the repeated firing in the industrial kilns marks the completion of a certain stage more nearly than heating at 1600°C for only half an hour. Be that as it may, the differences are evident. The comparison of the values also proves

TABLE I
PROPERTIES OF SILICA BRICK MADE BY GERMAN FACTORIES

No.		Specific gravity	LOAD TEST 1 kg. sq. cm. *a*. Temperature of rupture, (old lever press). *b*. Softening temperature (Dr. Steger's press) in °C	LINEAR EXPANSION after heating ½ hr. at 1600°C in %	MICROSTRUCTURE Content in %		
					Quartz (plus silicates)	Cristobalite	Tridymite
1	A 1 Basic Open Hearth Furnace Type	2.40	*b* 1550°	3.3	28	70	ca 2
2		2.40	*b* 1550	3.5	23	75	ca 2
3		2.38	*b* 1540	2.8	25	72	ca 3
4		2.48	*b* 1555	3.3	29	70	ca 1
5		2.50		4.5	40	60	. .
6		2.42	*b* 1520	3.2	16	82	ca 2
7		2.37	*b* 1525	2.2	14	82	ca 4
8		2.40	*b* 1530	3.4	22	78	. .
9	By-Product Coke Oven Type	2.49	*b* 1470	4.5	30	70	. .
10		2.48	*b* 1455	5.0	34	46	. .
11		2.46	*a* 1620	3.8	35	65	. .
12	Glass Furnace Type	2.47	*a* 1600	4.0	40	60	. .

TABLE II
PROPERTIES OF SILICA BRICK

No.		Specific gravity	LOAD TEST 1 kg. sq. cm. *a*. Temperature of rupture (old lever press). *b*. Softening temperature (Dr. Steger's press) in °C	LINEAR EXPANSION after heating ½ hr. at 1600°C in %	MICROSTRUCTURE Content in %		
					Quartz (plus silicates)	Cristobalite	Tridymite
13	Made by *German Steel Works* for private consumption	2.38	*a* 1620°	1.4	13	82	<5
14		2.35	*a* 1655	0.4	16	80	ca4
15		2.33	*a* 1670	1.0	10	85	5
16	A 1 Quality	2.32	*a* 1620	0.8	13	82	5
17	A 2 Quality	2.36	*a* 1605	0.6	11	85	4
18	*U. S. A.* Made from Medina Quartzite "Star"	2.34	*a* 1620 *b* 1535	0.5	14	81	5

19	Made from Baraboo Quartzite	2.33	.....	..	13	82	5
	England						
20	Made from English Silica Ganisters	2.40	*a* 1660	3.1	25	70	<5
21		2.40	*b* 1670	4.0	19	76	<5
	Sweden						
22	Made from Swedish Quartzite	2.39	*a* 1620	4.0	18	77	<5
23		2.34	*a* 1650	1.7	15	80	<5

that American silica brick, made of typical rock quartzites, show the same valuable properties as do German silica bricks made of the best erratic-block quartzites. As a matter of fact, therefore, the question of the nature of the quartzite raw material does not seem to be of prime importance, as long as, after proper mixing of the ingredients, the time of heating and the temperature of heating are, respectively, sufficiently long and high.

Among the different German products the brick made by the great German steel works themselves are, as may be proved, usually better than the trade products of refractory works. The reason for this may possibly be that the great steel works with factories of their own are makers and users at the same time and have no need for making an intermediary profit, as the refractory trade works must. The former are therefore able to use coal for firing purposes in more generous proportions and to fire longer and to higher temperatures than the latter.

In attempting to formulate certain *minimum requirements* from the figures given for the testing of silica brick, we arrive, on the basis of my experiments, at limiting values similar to those which Mr. D. W. Ross has already formulated from his experimental results.

In accordance with American usage, I should consider it advisable to make no distinction in the quality of the silica brick used for steel furnaces and those for by-product coke ovens. Such a distinction is still made in Germany, where very often, much to the detriment of the life of the coke oven plants, the ovens are still supplied with a No. 2 grade of silica brick. At most it is only in the case of silica brick for glass tanks that other qualities and conditions may be demanded as with these the density is of greater value than a high temperature of rupture or softening.

In formulating the minimum requirements for finished silica brick I will, therefore, exclude silica brick for glassmaking purposes. On the basis of my experimental results I suggest the following specifications for A 1 silica brick:

1. That the pycnometrically determined specific gravity of the finely pulverized substance be at least 2.38.

2. That the temperature of rupture under load conditions of 1 kg. per sq. cm. measured according to the old method be at least 1620°C, and that the softening temperature under the same conditions according to the new Dr. Steger lever press method be at least 1520°C. I do not, however, believe that this test is necessary for silica brick.

3. That the testing of the linear expansion after heating $1^1/_2$ hours from 20° to 1600°C, the test being kept constant for half an hour at 1600°C according to the method adopted shall not produce a linear expansion of more than 2 per cent.

4. That on examination of the microstructure in a thin section the content of unchanged quartz (and silicates) determined by means of a grating shall not exceed 15 per cent. It is desirable that the tridymite content be at least 5 per cent.

I have the honor to offer these suggestions for discussion by the American Ceramic Society and should be glad if my experiments, together with those of American investigators, should lead to the formulation of uniform testing methods for silica brick.

Technische Hochschule
Charlottenburg, Germany

DISCUSSION OF THE PAPER ON "TESTING OF SILICA BRICK" BY DR. KURD ENDELL PRESENTED AT THE ST. LOUIS MEETING OF THE AMERICAN CERAMIC SOCIETY

Fred A. Harvey and E. N. McGee

This very carefully worked out paper has been especially interesting to us because it covers the same general ground as we have covered in our own tests during the past few years. We should like to discuss the following points. **1. Specific gravity.** In our work the apparent specific gravity has been the value more frequently determined and is the value used in our published work. In this method the sample is boiled for an hour and a half under a vacuum of at least 20 inches of mercury, and we have found that the method yields very consistent results. This value is about .02 lower than the true specific gravity as determined by Dr. Endell. This fact must be born in mind in making comparisons. **2. Residual Linear Expansion.** In all of our tests for determining residual linear expansion the sample was heated very slowly to 1450°C and maintained at this temperature for 72 hours. Repeated tests at various lengths of time show that this time and temperature will reduce the specific gravity practically to its minimum value, thus bringing out practically all the residual linear expansion. It is American practise to heat clay brick for 5 hours at 1400°C to determine expansion or contraction, but we are not aware that anyone has used 4 hours at 1400°C to determine residual expansion in silica brick as assumed by Dr. Endell. This time and temperature certainly would not bring the brick to its final state. We doubt if Dr. Endell's rate of heating to 1600°C in $1^1/_2$ hours is slow enough to give consistent results on residual expansion even on the small samples which he used. Our own experience indicates that a much slower rate is necessary. The results in Dr. Endell's paper do not in general check well with the chart published by us. We have already tested two samples of English Silica Brick and three Australian silica brick. This is hardly a sufficient number to draw any definite conclusions. The results obtained on the Australian samples did not check up with any of our results on American brick. The apparent density appeared to be considerably lower than for American bricks for the same percentage of expansion as determined by the reheating test—72 hours at 1450°C. The English bricks, however, checked up better and it would appear that a larger number of results would show them to be in very good agreement. **3. Hot Crushing Strength.** The values of hot crushing strengths as determined on American bricks by A. S. T. M. method C-16-20 give considerably higher results than those given by Dr. Endell for German and American Silica Bricks.

We would be very much interested in subjecting some of the German Silica Bricks to our American Tests.

Preparation of Abstracts

Every article in THIS JOURNAL is to be preceded by an abstract prepared by the author and submitted by him with the manuscript. The abstract is intended to serve as an aid to the reader by furnishing an index and brief summary or preliminary survey of the contents of the article; it should be suitable for reprinting in an abstract journal so as to make a reabstracting of the article unnecessary. The abstract should, therefore, **summarize all new information completely and precisely.** Furthermore, in order to enable a reader to tell at a glance what the article is about and to enable an efficient index of its subject matter to be readily prepared, the abstract should contain **a set of subtitles** which together form a **complete and precise** index of the information contained in the article. This requires at least one and often several subtitles even for a short abstract.

In the preparation of abstracts, authors should be guided by the following rules, which are illustrated by the abstracts in THIS JOURNAL for February and March, 1921.* The **new information** contained in an article should first be determined by a careful analysis; then the subtitles should be formulated; and finally the text should be written and checked.

Rules

1. **Material not new** need not be analyzed or described in detail; a valuable summary of a previous work, however, should be noted with a statement indicating its nature and scope.

2. **The subtitles should together include all the new information;** that is every measurement, observation, method, improvement, suggestion and theory which is presented by the author as new and of value in itself.

3. **Each subtitle should describe the corresponding information so precisely** that the chance of any investigator being misled into thinking the article contains the particular information he desires when it does not, or vice-versa, may be small Such a title as "A note on blue glass," for example, is evidently too indefinite a description of information regarding "Absorption spectra of glass containing various amounts of copper-cobalt and chromium-cobalt." General subtitles, such as "Purpose" and "Results" should not be employed as they do not help to describe the specific information given in the article.

4. **The text should summarize the authors' conclusions and should transcribe numerical results of general interest,** including those that might be looked for in a table of physical and chemical constants, with an indication of the accuracy of each. It should give all the information that anyone, not a specialist in the particular field involved, might care to have in his note book.

5. **The text should be divided into as many paragraphs** as there are distinct subjects concerning which information is given, but no more than necessary. All parts of subtitles may be scattered through the text but the subject of each paragraph, however short, must be indicated at the beginning.

6. **Complete sentences** should be used except in the case of subtitles. The abstract should be made as readable as the necessary brevity will permit.

7. The ms. of all abstracts must be typewritten and double or triple spaced.

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* The rules were prepared by the Research Information Service of the National Research Council. The Society is indebted to Dr. G. S. Fulcher of the Corning Glass Works (formerly with the National Research Council) for the rules and the illustrative abstracts.

JOURNAL
OF THE
AMERICAN CERAMIC SOCIETY

A monthly Journal devoted to the arts and sciences related to the silicate industries.

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Vol. 5 **May, 1922** **No. 5**

ORIGINAL PAPERS

REDUCTION OF VARIETIES IN MANUFACTURED PRODUCTS[1]

By E. W. McCullough

I appreciate both the pleasure and honor of addressing your organization which in another year will have completed a quarter of a century's activities in behalf of the many lines grouped under the heading "ceramics."

I desire to deal with my subject almost wholly from a commercial economic angle rather than the scientific, although to a very great extent the economies to be accomplished will be gained through the recognition of fundamental engineering principles in establishing standards.

It is common knowledge that in the world's industrial development the production of most of our common commodities has been from very crude beginnings, improving step by step through the acquisition of skill on the part of the operative and in many instances without the recognition of scientific principles except in a very general way. The father transmitted to his sons the knowledge he developed in his labors beginning with the raw materials and ending with the product in its finished state. Perhaps in few lines has this been more true than in the manufacture of various ceramic products.

With the introduction of power machinery, for the first time it was realized that certain laws and principles would have to be recognized in creating new designs and bringing about mass production, but even this step did not cause the research necessary to develop a conviction that it would be advisable to go back to first principles and build the manufacture of each commodity on a scientific basis; consequently there is today in the manufacture of many commodities much waste that can be eliminated.

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[1] Address delivered by E. W. McCullough, Manager, Fabricated Production Department, U. S. Chamber of Commerce, to the Twenty-fourth Annual Meeting of the American Ceramic Society, St. Louis, Missouri, Feb. 27, 1922.

The early wagon-maker with knowledge gained by experience in working woods and metals, built crude but sturdy vehicles, relying wholly on his experience in blacksmithing to determine whether he should use a half-inch round rod for bracing or whether it should be five-eighths or three-quarters. If he erred, it was usually on the side of using more materials, not less, but as materials today have more than doubled in cost in most instances, it becomes necessary to analyze the construction of this man's work and determine how far his material requirements can be reduced and at the same time retain the strength and service required.

With the use of machinery it was realized that the fundamental of low cost production was small variety and large volume and for a time this rule was well adhered to, but with the various changes in marketing conditions and the seeking of trade in more distant territories there grew up a marked tendency to the increase of variety.

One instance in your own lines will suffice to illustrate. The paving brick manufacturers and engineers recently met in coöperation to reduce variety which had grown in that line to the number of sixty-six, and they were able by fully realizing the situation to reduce this number to eleven, thereby casting out fifty-five styles, sizes and kinds.

Secretary Hoover in addressing them preliminary to their action, said:

> The proposal that you are considering is no new idea in American industry, but it comes up in its best form on this occasion because it is inspired by the manufacturers themselves.
>
> I think the engineers, of whom I have long been one, have been united in the feeling that there is a great area of waste in American industry that can find correction only at the hands of the manufacturers and can find it only in a purely voluntary action on their part.
>
> We are, in a broad sense, confronted with a great many economic difficulties—the necessity to maintain a high wage level, the consequent necessity to reduce all processes of manufacture to the lowest possible costs, and under the compulsion of eliminating every possible waste of industry itself. There is one thing that stands out about American industry that comes up daily to the Department, and that is the remarkable efficiency of the individual industry and the very considerable inefficiency of collective industry. If we had the same native efficiency collectively in this country that we have individually, we would have no difficulty in maintaining our own in foreign or international commerce, of maintaining the high wage levels and the high standards of living, and it is only by virtue of some prompt action that we can hope to secure some fundamental readjustments that the country must have.

There has been a great lack of coöperation and coördination between the production and sales departments of many manufacturing organizations and perhaps a lack of backbone in the management in permitting either the manufacturing department or the sales department to predominate in determining the lines which should be made or the changes and variations to be made in standard lines which had been adopted.

The slogan "We make what our trade calls for" is equally as fruitful of trouble as the slogan of a famous retailer "The customer is always right." I would cast no reflection on those who watch carefully the trend of their customers' thought and seek to provide what will best meet their real needs, for such vigilance is most certain to be rewarded by continued dealings and confidence on the part of the customers, but this is quite different than chasing whims and fancies, whether it be those of the consumer or some division of the distributing agency which seeks continually to present something new and novel, whether or not there is any merit in it. Perhaps there is no agency which has been more responsible for the large and wasteful variety found in many manufactured lines today than the over-ambitious sales organization which can see nothing but volume of orders and takes no thought of whether or not what they take orders for will net a profit or a loss.

One large concern in the iron and steel lines discovered that their catalog was rapidly growing, but out of all proportion with their profits, and decided to analyze their stock to discover just what lines were most greatly in demand and profitable. Their catalog at that time contained 17,000 items and the result of their inquiry revealed the fact that but 614 lines were being produced in profitable volume. The remainder was made up largely of special patterns either to imitate those of their competitors or with the hope that they would develop into larger volume. That concern is today employing part of the time of its sales forces in having their customers realize the advantages of standardization and the reduction of variety to the end that there may be not only dollar and cents economy but great improvement in service.

In the investigations which my department of the United States Chamber of Commerce has been making for something over a year, we have found that excess variety in some lines obtains to such an extent that factories have almost been reduced to the level of hand shops, in other words, the runs are so short and the machine changes so frequently and the demoralization of labor is so great that costs and overhead have mounted to such a height that there is not a wide difference between the costs of the factory and the custom-made products referred to.

In the years which preceded the war we drifted more or less unconsciously into this matter of great variety through, perhaps, the great stress which was laid on the individuality of products by advertising. There was a very general tendency in certain kinds of advertising to emphasize particular brands not only as to the merits of manufacture, but by the assurance that they were designed to meet individual needs more nearly than that of their competitors. There was unquestionably a tendency to try to convince the consumer that they could meet his every need in the variety they offered him to select from.

Perhaps this situation was most fully realized when the Conservation Division of the War Industries Board took hold to save money, materials and men when we entered the world's conflict. Their first analysis of the situation showed how badly overdone this matter of variety was particularly when they looked into many lines of personal wear. They found, for instance, in the matter of shoes that there were as many as seven shades of tan colored leather. Their judgment was that one light shade and one dark shade was sufficient. They went into clothing lines, rubber coats and numberless other articles and made equally drastic reductions.

We lived through the war, suffering no inconvenience whatsoever on this reduced variety, but just as soon as the Government's hand was lifted from the enforcement of these restrictions, the old-time clamor for more variety returned and many of the lines which benefited greatly by enforced reduction are now suffering as they did before from excessive variety.

At a recent meeting held in the Department of Commerce at which prominent architects, builders and engineers were present, the question of reducing varieties in building trade commodities was the principal subject of consideration. It had been claimed that the classes to which these men belonged had been largely responsible for the wasteful varieties which obtain in building commodities at this time. Undoubtedly they contributed as did all other elements to the excess, but they were found to have very great willingness at this time to lend their assistance and bring about reduction at the earliest possible moment. Suitable resolutions setting forth their attitude were passed and the following items were named which should receive the earliest attention: millwork, plumbing, heating, interior wall construction, hardware, lighting fixtures and clay products, the latter comprehending all ceramic productions used in building construction.

Some of these lines have already organized and have made considerable progress and it is expected that because of the attention which will be given them, practically all others will sooner or later fall in line. We are all aware of the difficult housing situation throughout the country and that building has been held up for several years to the detriment of our people in many ways, and it is high time that something practical should be done to make resumption in building possible. It is believed that with the economies which can be worked out in building material lines, a very considerable reduction in cost will most certainly follow.

At the risk of rambling a bit, I desire to cite you an instance in the farm implement line where by reason of following a program of standardization and elimination one large concern this year was able to reduce its inventories at the factory and in various portions of the country 30 per cent.

and their normal inventory being nearly $15,000,000, their saving in capital alone can be appreciated, but the president of the concern makes the further significant statement that they are now carrying a better assorted stock than ever before and are in position to serve their dealers and the farmers more efficiently than at any time in their career. In that line the eliminations numbered 955 and types retained 137.

Here are some of the gains to the manufacturer:

1. Less capital tied up in (*a*) Raw materials, (*b*) Semi-finished stock, (*c*) Finished stock, (*d*) Jigs, dies, templates and special machinery, (*e*) Storage floor space, (*f*) Repair parts.

2. More economical manufacture through (*a*) Larger units of production; reduced number of manufacturing units, (*b*) Longer runs, less frequent change, (*c*) Higher rates of individual production, (*d*) Accurate and proper estimating for production, (*e*) More effective stock control, (*f*) Better and more simplified inspection, (*g*) Less idle equipment; reduced amount of equipment, (*h*) Greater ease in securing raw materials, and conserving raw products, (*i*) Cheaper handling of stock, (*j*) Reduced clerical overhead, (*k*) Simplified and more accurate costing system, (*l*) Elimination of waste in experimentation and design, (*m*) Standardized material inventories.

3. More efficient labor due to (*a*) Making training of employees more simple, (*b*) Better earnings, through increased individual production made possible by longer runs, (*c*) Happier and more contented workmen, (*d*) Skill increased by repetitive process, (*e*) Less labor idle from preventable causes, (*f*) More permanent employment as contrasted to present seasonal employment.

Points of economic and industrial significance:

1. It enables buyer and seller to speak the same language, and makes it possible to compel competitive sellers to do likewise.

2. Better quality of product through ability of manufacturer to concentrate on better design and through the reduction of manufacturing expense.

3. It lowers unit cost to the public by making mass production possible, as has been so strikingly shown in the unification of incandescent lamps and automobiles.

4. By simplifying the carrying of stocks it makes deliveries quicker and prices lower.

5. It decreases litigation and other factors tending to disorganize industry, the burden of which ultimately falls upon the public.

6. It eliminates indecision both in production and utilization—a prolific cause of inefficiency and waste.

7. It stabilizes production and employment, by broadening the possible market, and by making it safe for the manufacturer to accumulate stock during periods of slack orders to an extent which would not be safe with an unstandardized product.

8. By focusing on essentials, it decreases selling expense: one of the serious problems of our economic system.

9. By concentrating on fewer lines, it enables more thought and energy to be put into designs, so that they will be more efficient and economical.

As a result of the activities of the Chamber in coöperation with the Department of Commerce several hundred commodity lines are today studying this subject of simplification of variety and standardization, and many of them are making notable progress, in fact in several instances the results are comparable with what was done in the paving brick case. Concerns manufacturing not only for domestic trade, but for trade abroad, have become aware that the Germans began immediately following the close of the war to study dimensional standardization with reference to practically all their commodities, and in this study finally reached the point where they appreciated the value of eliminations and have been pursuing that angle as well.

This country is very largely responsible for what is commonly known as "mass production," in fact it is because of our ability to produce good goods in large quantities at low cost that we have been able to invade the markets of the world, many of which change very slowly, and we should not have their trade today if it were not for our ability to produce satisfactory goods at the right prices, but we believe there is real danger in what we have pointed out, that as we increase varieties we can not get mass production in the broadest sense, and we shall lose much of our efficiency unless a careful study is made in every line to meet the needs of the consumer and to disregard to a reasonable extent mere whims and fancies.

Some misunderstanding and perhaps confusion has occurred as to what is meant by standardization when closely coupled with the terms "eliminations" or "simplification" of variety. It should, however, be clear that no attempt is being made to standardize or reduce commodities to a common pattern—they will continue to embody the distinctive design and form of the producer but will avoid needless duplications and the making of near sizes which make for waste. There will also be standardization of non-competitive parts such as stove legs and lids, wheel diameters, and such other parts as may be made interchangeable to advantage.

Just a word in closing, to suggest that all the efforts which are being made to have the evil we have referred to recognized are purely of a voluntary character. The control over variety in manufactured products ceased with the close of the war, and whatever may be done to clean up the various lines and place them in better condition for economical production, sale and distribution must be wholly by those who produce and distribute them.

Perhaps it may not be amiss for me to say a word as to the connection of the Chamber of Commerce of the United States through its Fabricated Production Department with these activities. The Chamber in its nearly ten years of service to business, about three years ago felt that it might increase this service through the creation of eight new departments to deal with the more intimate problems of commerce and industry and to that end created departments to deal with such problems as that of finance, raw materials, fabricated production, insurance, foreign commerce, civic development, transportation and communication, and domestic distribution. These departments are all in charge of experienced men and staffs of employees devoting their entire time to dealing in a non-partisan way with such common problems as invite attention.

It is our desire to so coöperate with your own great organization as to make available to you this additional service developed in fields somewhat broader and more general than your own but none the less valuable.

BERYL AS A CONSTITUENT IN HIGH TENSION INSULATOR PORCELAIN

BY ROBERT TWELLS, JR.

ABSTRACT

Beryl as a Constituent in High Tension Insulator Porcelain.—Two series, one of 9 bodies and one of 6, were prepared, in which flint and feldspar were partially replaced, weight for weight, by beryl. Bars and discs were fired to cone $8^3/_4$, to 10, or to $10^3/_4$ and tested for *shrinkage, transverse strength, impact strength, heat resistance, absorption of moisture,* and *dye penetration.* The results show that introduced in proper proportions beryl increases the transverse strength, impact strength, heat resistance and dielectric strength. The best results are obtained with the following limits of composition:

Clay	48.54%
Feldspar	13.30 to 23.98%
Flint	0.0 to 5.83%
Beryl	21.65 to 37.63%

Previous Investigations

Bleininger and Riddle[1] have reported that beryl used as a flux gives porcelains having high electrical resistance, high Te[2] values and low thermal expansion. The three bodies reported had the relatively low firing temperature of cones 11 and 12. Aside from this article there seems to be little published information in regard to the use of beryl in porcelain. At the General Electric Company, however, several investigators have done work on this subject.

Treischel[3] reported that beryl when substituted for flint gave a body of high dielectric strength, high resistance to temperature changes, high mechanical strength and low absorption. Leibson[4] covered a series replacing feldspar and flint partially with beryl. He reported satisfactory results similar to Treischel's.

Twells and Lin[5] made up three bodies containing calcined beryl and tested them in comparison with a standard triaxial porcelain. Their results at cone $9^3/_4$ can be summarized as follows:

(1) The standard porcelain was non-porous. It had high mechanical strength, fair dielectric strength, fair resistance to temperature changes and good resistance to impact.

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[1] A. V. Bleininger and F. H. Riddle, *This Jour.*, **2**, 564 (1919).

[2] Temperature in degrees C at which a cubic centimeter of material still shows a resistance of one megohm.

[3] Chester Treischel, Research Department Report, General Electric Company, May, 1918.

[4] J. S. Leibson, Research Department Report, General Electric Company, November, 1919.

[5] Robert Twells, Jr., and C. C. Lin, Research Department Report, General Electric Company, September, 1920.

(2) When half of the K_2O in the RO of the standard porcelain was replaced by BeO, the Al_2O_3 and SiO_2 being held constant, the body was not vitrified. As a result, all of its properties were low except the resistance to temperature changes which was very high.

(3) When all the K_2O in the RO of the standard porcelain was replaced by BeO, the Al_2O_3 and SiO_2 being held constant, the porosity was farther increased. This resulted in greatly lowering all of the properties including the resistance to heat changes.

(4) When the feldspar in the standard porcelain was replaced by beryl. on a pound for pound basis, the porosity was even greater than that of the other two beryl bodies. The properties of this body were almost the same as when the K_2O was totally replaced molecularly by BeO, but the color in this case was cream and the resistance to heat changes was better.

The conclusions from the results by these investigators are:

(1) BeO has not nearly the fluxing action of K_2O when used to replace it molecularly in large percentages.

(2) Beryl is not equal to feldspar in fluxing action when used to replace it pound for pound in large percentages.

(3) Beryl is a valuable constituent in a semi-vitreous porcelain which must resist heat changes.

Present Investigation

SERIES I

Purpose.—The purpose of this series was to check and extend results of Treischel and of Leibson, replacing the flint and feldspar, pound for pound, with beryl while maintaining a constant clay content.

SOURCES OF RAW MATERIALS

Flint, Pennsylvania Pulverizing Co.
Feldspar, Eureka Flint and Spar Co.
Beryl, Foote Mineral Co.

TABLE I

COMPOSITION OF THE BODIES

Body number	Per cent clay	Per cent beryl	Per cent feldspar	Per cent flint
1	48.54	...	33.98	17.48
2	48.54	5.83	33.98	11.65
3	48.54	11.63	33.98	5.83
4	48.54	17.48	33.98	...
5	48.54	22.48	28.98	...
6	48.54	27.48	23.98	...
7	48.54	32.48	18.98	...
8	48.54	21.65	23.98	5.83
9	48.54	10.83	28.98	11.65

Preparation and Methods of Testing.—The corner members of the series, numbers 1, 4 and 7, were weighed out and blunged thoroughly. From these the remainder of the bodies of this series were made up by cross-blending. The preparation and testing of the bodies were performed exactly as has been already described in the *Journal* in an article by Twells and Lin.[6] For the resistance to heat changes the second method described was used.[7]

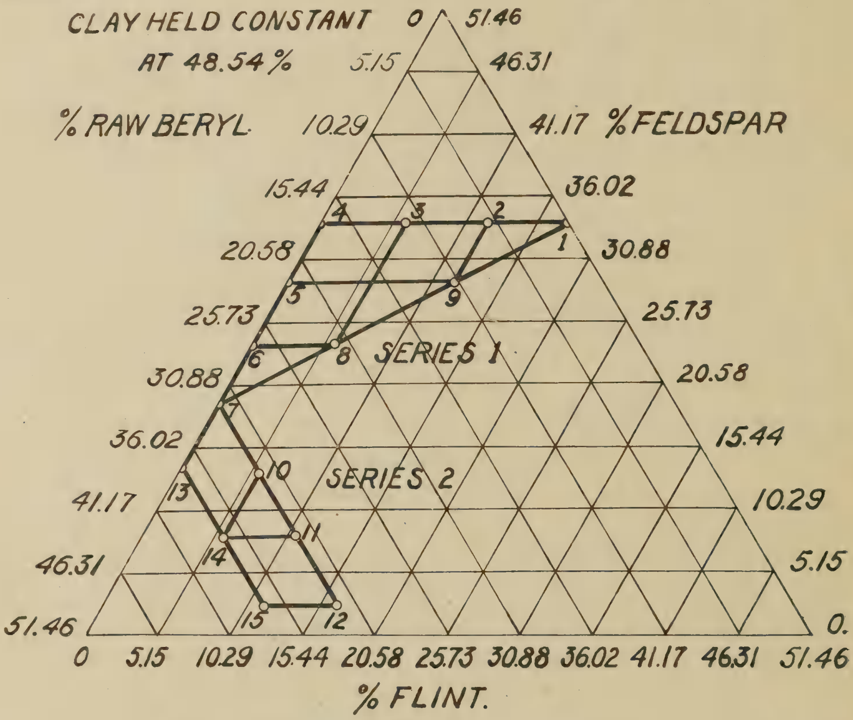

Fig. 1.

Drying and Firing.—The test pieces were thoroughly air-dried and then placed in saggers with standard cones. They were fired in a round up and down draft periodic kiln to cone $10^3/_4$ in 51 hours.

Table II

Summary of Data (Cone $10^3/_4$)

Body number	Shrinkage per cent of wet length			Absorption per cent of dry weight			Dye test	Color
	Drying	Burning	Total	Min.	Max.	Av.		
1	6.1	11.3	17.4	0.07	0.07	0.07	NP	White
2	5.5	10.2	15.7	0.07	0.11	0.08	NP	White
3	5.4	9.8	15.2	0.08	0.10	0.09	NP	White
4	4.9	9.0	13.9	0.07	0.11	0.09	NP	White

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[6] Robert Twells, Jr., and C. C. Lin, *This Jour.*, **4,** 195 (1921).

[7] *Ibid.*

5	5.5	9.1	14.6	0.06	0.08	0.07	NP	White
6	5.4	9.6	15.0	0.06	0.08	0.07	NP	White
7	4.9	10.9	15.8	0.06	0.07	0.07	NP	White
8	6.1	10.5	16.6	0.07	0.10	0.08	NP	White
9	5.7	11.5	17.2	0.05	0.07	0.06	NP	White

TABLE III

Body no.	MODULUS OF RUPTURE LBS. PER SQ. IN.			RESISTANCE TO IMPACT INCHES OF DROP			RESISTANCE TO TEMPERATURE CHANGES NO. OF HEATS STOOD		
	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.
1	4720	7940	6440	14.0	38.5	25.0	8	9	8.0
2	6690	8000	7270	26.0	37.5	32.5	6	10	8.5
3	5810	8740	6880	20.0	35.0	27.5	7	23	14.0
4	4290	7340	5770	12.0	28.0	17.0	8	Over 25	Over 14.0
5	6380	7860	6940	18.5	37.0	27.5	4	Over 25	Over 14.8
6	4870	7860	6450	18.5	35.0	27.5	8	Over 25	Over 20.8
7	6200	8650	7110	21.0	37.0	29.5	14	Over 25	Over 22.2
8	6650	9150	7890	23.5	44.0	36.0	8	Over 25	Over 19.6
9	4800	7310	6300	20.0	26.5	23.5	6	Over 25	Over 12.6

Comments on Results

Firing Shrinkage.—The substitution of beryl for flint, with feldspar constant, decreases the burning shrinkage. The substitution of beryl for feldspar, with flint constant, increases the burning shrinkage.

Absorption.—All of the bodies are thoroughly vitrified but are not overfired.

Mechanical Strength.—The replacement of flint by beryl, with feldspar constant, tends to lower the transverse strength and the resistance to impact. The replacement of feldspar by beryl, with flint constant, tends to raise the transverse strength and the resistance to impact.

Resistance to Heat Changes.—The substitution of beryl for either flint or feldspar increases the resistance to temperature changes; this resistance increasing with increasing percentage amounts of beryl.

Effect of Proportions.—Properties better than those of the standard porcelain are obtained only with certain proportions of flint, feldspar, and beryl. For example, replacement of flint by beryl in the standard porcelain produces an inferior porcelain; yet if the beryl is at the same time increased at the expense of the feldspar, a very superior porcelain (No. 7) is produced, which contains no flint.

The best body (No. 8) contains a small percentage of flint, and the third best body (No. 2) contains only a small percentage of beryl.

Present Investigation

SERIES II

Purpose.—Bleininger and Riddle[8] gave the following formula of a spark plug porcelain maturing at cone 11:

Kaolin	40%
Ball clay	10%
Flint	15%
Beryl	35%

As this porcelain was much different from those previously tried, it was thought well to cover the area on the triaxial diagram lying between this body and the area previously covered. Preliminary experiments had shown the inadvisability of totally omitting the feldspar in a porcelain to mature between cones 9 and 11. The minimum percentage of feldspar used in this series was 2.46%.

TABLE IV

COMPOSITION OF THE BODIES

Body number	Per cent clay	Per cent beryl	Per cent feldspar	Per cent flint
10	48.54	32.48	13.30	5.68
11	48.54	32.48	8.15	10.83
12	48.54	32.48	2.46	16.52
13	48.54	37.63	13.83	...
14	48.54	37.63	8.15	5.68
15	48.54	37.63	2.46	11.37

Procedure.—These bodies were made up similarly to series I, by blending the four corner bodies, 7, 13, 12, 15. The method of preparing the test pieces, placing in saggers and firing was the same as before. Temperatures of cones $8^3/_4$ and 10 were obtained. The writer was unable to complete all the tests on this series. This was unfortunate since the results of some important tests are missing.

TABLE V

SUMMARY OF DATA

	SHRINKAGE PER CENT OF WET LENGTH CONE $8^3/_4$			ABSORPTION PER CENT OF DRY WEIGHT	
Body number	Drying	Burning	Total	CONE $8^3/_4$ Av.	CONE 10 Av.
1	5.3	8.2	13.5	0.02	0.01
7	5.0	9.5	14.5	1.11	0.03
10	3.7	9.3	13.0	1.68	0.02
11	4.0	9.2	13.2	2.74	0.26
12	4.0	7.2	11 2	8.75	3.54
13	4.8	9.2	14.0	1.85	0.04
14	4.8	8.7	13.5	3.53	0.69
15	4.7	6.3	11.0	7.83	2.65

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[8] A. V. Bleininger and F. H. Riddle, *This Jour.*, **2,** 564 (1919).

TABLE VI

SUMMARY OF DATA

Body number	MODULUS OF RUPTURE CONE $8^3/_4$ LBS. PER SQ. IN. Av.	CONE 10 Av.	COLOR
1	7940	7860	White
7	7120	7150	White
10	7180	8760	White
11	5750	6310	White
12	4560	5040	White
13	6530	8180	White
14	6030	7600	White
15	7120	6060	White

Comment on Results

Firing Shrinkage.—In the area covered, the substitution of beryl for either flint or feldspar decreases the burning shrinkage. This is due to decreased vitrification.

Absorption.—Cone $8^3/_4$—All the bodies in the area covered are very porous at this temperature. The absorption increases with the increase of either flint or beryl at the expense of the feldspar. Cone 10—Bodies 7, 10 and 13 are vitrified at cone 10. The other bodies of the series are porous at this temperature. The replacement of the feldspar by either flint or beryl increases the absorption but the beryl tends to increase the absorption at a greater rate than the flint except with low feldspar content. In this series a minimum of 13.30% of feldspar was needed for vitrification at cone 10.

Mechanical Strength.—The transverse strengths of all the bodies are closely dependent on their degree of vitrification. The transverse strength of the standard body (No. 1) is much increased at cone $8^3/_4$ and cone 10 over what it was in series I at cone $10^3/_4$, although the absorption is practically zero in each case. This tends to confirm what the writer had previously noted that this body had its best mechanical strength at the minimum temperature at which it was vitrified.

Body No. 7 has practically the same transverse strength at the three temperatures tried.

Body No. 13 shows a marked increase in transverse strength over No. 7.

No. 10 is better in transverse strength than No. 13 and it is also better than No. 8, the best one of previous series.

This confirms the results of the previous series, that the replacement, within limits, of feldspar by beryl increases the mechanical strength, and that flint, at least in small percentages, adds to the mechanical strength.

General Conclusions

Best Range of Composition.—Of the bodies tested in both series the best for use at cones 10 to 11 would seem to be bodies 7, 8, 10 and 13. These have the following range of composition:

Clay	48.54%
Feldspar	13.30 to 23.98%
Flint	0.0 to 5.83%
Beryl	21.65 to 37.63%

To judge only by the results of the transverse strength test, body No. 10 is the best, with No. 13 second. Since, however, all the tests were not completed on these bodies, it is necessary to regard No. 8 as the best all-round body developed. For this reason No. 8 was selected for comparison in the electrical test against the standard body (No. 1).

Dielectric Strength.—Test for dielectric strength was made in the manner described by Twells and Lin.[9] The averages of ten trials of each body are as follows:

No. 1, 150 volts per mil.
No. 8, 175 volts per mil.

Comparison of the Best Beryl Body with the Typical Electrical Porcelain Body.—A comparison of the results at cone $10^3/_4$ of the tests on the standard body (No. 1) with those on the best beryl body (No. 8) (both being vitrified) shows the value of beryl as a constituent of electrical porcelain. The beryl body (1) has less firing shrinkage, (2) is 22.5% stronger in transverse strength, (3) 44% more resistant to impact, (4) 17% stronger in dielectric strength, and (5) over 145% more resistant to the effect of temperature changes. It is not a difficult matter to improve a porcelain in one or two respects, but the data here given show that the introduction of beryl in certain proportions to the other constituents improves every property tested.[10]

Note: Patents assigned to the General Electric Co. covering the use of crude beryl in porcelain and ceramic insulating compounds are pending.

General Electric Company
Schenectady, N. Y.

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[9] Robert Twells, Jr., and C. C. Lin, *This Jour.*, **4**, 195 (1921).

[10] See also A. S. Watts, *Trans. Am. Ceram. Soc.*, **14**, 90–92 (1912).

ECONOMIC HANDLING OF MATERIALS IN PORCELAIN MANUFACTURE[1]

By A. P. Ball

It has long been recognized in the metal working industries that one of the most promising opportunities for effecting savings lies in mechanical methods of moving materials. Efficiently planned and equipped steel mills, automobile plants and the like have reduced to the minimum the manual handling of materials.

It appears to the writer that at least until very recently the ceramic industries have overlooked the advantages to be secured from efficient handling of materials, possibly because the establishment of these industries so far antedated the metal working industries which have so largely been responsible for the development of mechanical conveying systems.

Comparatively recent developments in ceramic engineering, such as tunnel kilns and continuous driers have, of course, incorporated the latest practice in mechanical movement of materials, but little has yet been done to apply these principles to methods and processes long established in the industry. It might therefore be of interest to outline the manner in which modern practice in handling materials in metal working industries was applied to a dry process electrical porcelain plant. The processes of manufacture used in this plant do not differ essentially from those in general use today in most plants manufacturing similar material. The savings which have been effected in operating this plant are due almost wholly to more efficient handling of materials and not due to changes in existing processes. The installation of a tunnel kiln, tunnel drier and other modern equipment would have made much the same saving in handling material but at a cost far greater. This large investment was not considered justifiable considering the age and condition of the buildings and equipment.

This porcelain plant, located at Peru, Indiana, was purchased shortly after the armistice to insure an adequate supply of electrical porcelain for the manufacture of switches at the company's main plant at Detroit, Michigan. The Works Engineering Department of this latter plant, familiar with modern material handling practice in metal working plants, was struck at once with the great possibilities of handling such bulky and heavy material mechanically. A study of other porcelain plants showed that little or nothing had been done along this line, and furthermore, with a few exceptions, all custom and tradition strongly opposed any change in this direction. The handling of clays by means of bucket conveyors was in occasional use, but the method of loading kilns manually, each man carrying a sagger into the kiln on his head, was virtually universal and it was declared unequivocally that any mechanical method was out of the

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[1] Read before White Wares Division, St. Louis meeting, Feb. 28, 1922.

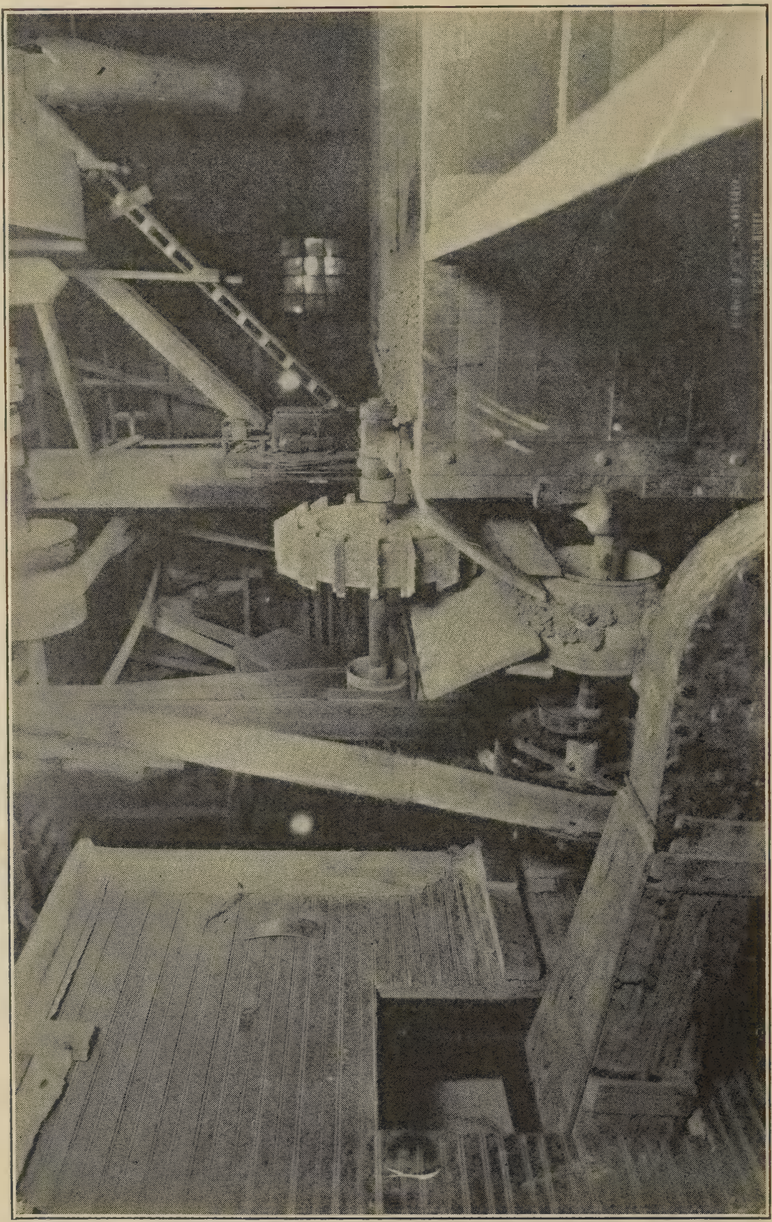

FIG. 1.—Tempering bins with belt conveyor for feeding dust mill. The crushed filter cakes are elevated by the inclined conveyor in the background to an overhead hopper from which the sheet metal pipe directs the crushed clay into the proper bin.

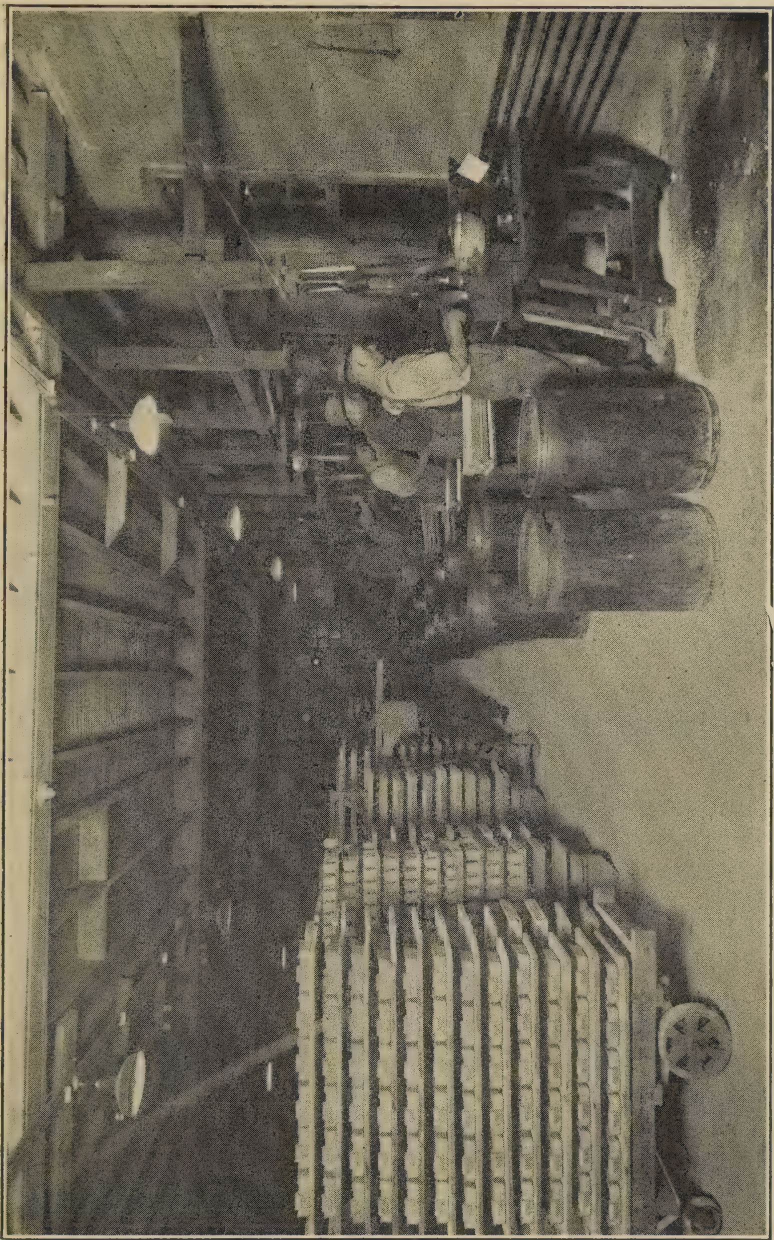

FIG. 2.—Scene in the Pressing Department. Dust is supplied to each operator in steel barrels; boards of pressed ware are loaded onto racks behind the operator. These racks are then moved to the drying room by means of a lift truck.

question. The methods devised for unloading cars of clay by portable bucket conveyors and loading blungers in a similar manner, not being novel, will not be described in detail. The other methods developed in our Peru Plant differed, so far as we can learn, from those in general use, hence will be described.

Use of Lift Trucks

One of the principal means of moving materials quickly and cheaply, and accepted generally in other lines of manufacture, is the lift truck. Skids were therefore made and used throughout the plant for storing all kinds of material except the raw clay. Frames were made to fit these skids for storing bulky material. These frames were 12″ wide and locked to the skid and to each other so that a container could be built up to any desired height. For dry pressed ware, which was delivered from the press and placed on boards, racks were secured to skids. These racks were made with two uprights carrying 10 horizontal supports made of $^3/_4$″ pipe on each side, affording room on each rack for 20 boards of ware. For the filter cakes a similar rack was made. Any racks or skids could be easily moved by one man by means of the lift truck. A total of about 600 skids and racks are conveniently handled in this plant by eight lift trucks. These various types of skids, skid frames and racks are shown in several of the accompanying illustrations.

From Filter Press to Pressing Department

Filter cakes as removed from the press are spread out flat on a rack carrying 20 removable boards. As fast as a rack is filled it is moved into a dry room. Formerly this dry room was equipped with stationary racks and the filter cakes were carried in and carried out, one board at a time. The new method eliminates not only carrying manually, but reduces in the proportion of about 1 to 20 the time a man has to be in the hot atmosphere of the dry room and also the time the door must be open, with the consequent drop in temperature. After drying, the rack of filter cakes is moved out to a crusher into which the contents of each board are dumped. The crushed material is elevated by a bucket conveyor to an overhead bin from which it is fed to any of three tempering beds where water is added as the bin is filled. From the tempering bins the material is shovelled onto a belt conveyor running across the end of each bin (Fig. 1) which feeds the dust mill. The dust is delivered into steel barrels which are placed on skids and moved to the Pressing Department by means of a lift truck.

From Press Room to Dryer

In this department one of the 20-board racks is placed behind each press operator with an aisle left between, as shown in Fig. 2. As soon as he fills a board he slides it into place on the rack. As soon as a rack is filled, the moveman moves it into a dry room and puts in place an empty rack so there is no interruption at any time to the pressing of the ware.

From Dryer to Sagger

As soon as the rack of ware is dry, it is moved to the cleaning room where it is placed at the end of a cleaning bench to the left of the operator. The operator, usually a girl, lifts a board from the rack to her bench where each piece is cleaned and put back on the board unless it also requires glazing. If it is to be glazed, it is passed on to the right to the next operator who dips it and places it back on the board. The dust is carried away by exhaust hoods set in the benches at each operating position. After glazing the board is placed on an empty rack at the opposite end of the bench. A view in the Cleaning and Glazing Department is shown in Fig. 3. After the rack is full, it is moved to an electric platform elevator which lowers it to the loading dock on the ground floor where the ware is placed in saggers.

Conveying to Kilns

Just as in cleaning, the rack is placed adjacent to a loading bench, but behind the operator and at the end of the bench is placed a skid of saggers, as shown in Fig. 4. The placer takes one board of ware from the rack and a sagger from the skid and places the ware in the sagger. As soon as the sagger is loaded it is lifted on a belt conveyor running along the end of the bench at the same level on the left of the placer. The conveyor, as hereafter described, delivers this sagger into the center of the kiln which is being loaded at the time. The placer has to exercise care to see that each loaded sagger is placed on the belt conveyor not less than 4 ft. from the next sagger so that they will arrive in the kiln at a uniform rate. This is accomplished by marking the belt every four feet and requiring that one sagger only be placed between any two marks.

Loading of Kilns

The belt conveyor for loading the kilns presented a rather serious problem. In spite of the prevalent opinion to the contrary, it was easily demonstrated that a straight-away conveyor could be built which would transport saggers loaded with ware in perfect safety. Experiments showed that by spacing the rollers close together, even fairly unstable pieces of ware would ride without tipping over, and that the vibration would not crack the ware or chip adjacent pieces that came in contact. The problem was rather to devise a means for transferring a loaded sagger from the main conveyor to a conveyor traveling at right angles to it and leading into the kiln. This turn had to be made without undue jarring which would

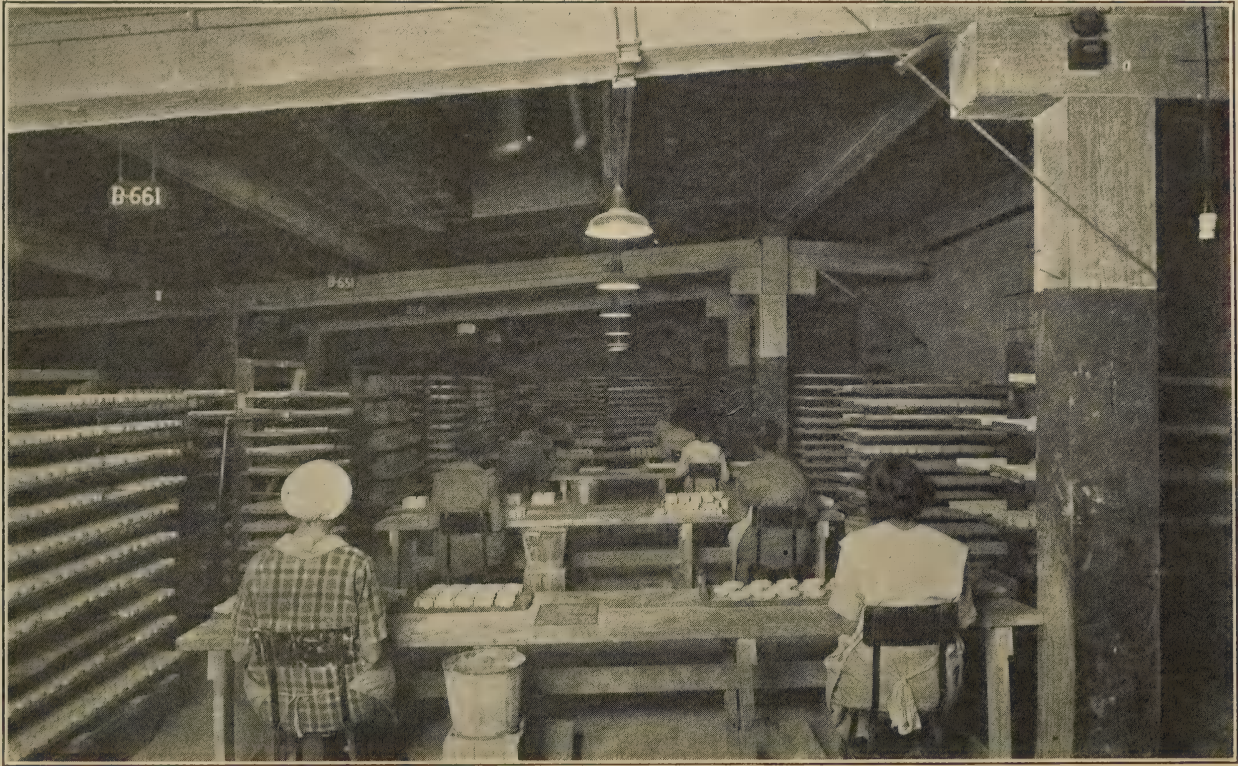

FIG. 3.—View of the Cleaning and Glazing Department. Ware to be cleaned is delivered on racks to the end of each bench and is replaced on the same racks after cleaning. An exhaust system with the opening directly in front of each operator carries off the objectionable dust from the cleaning operation.

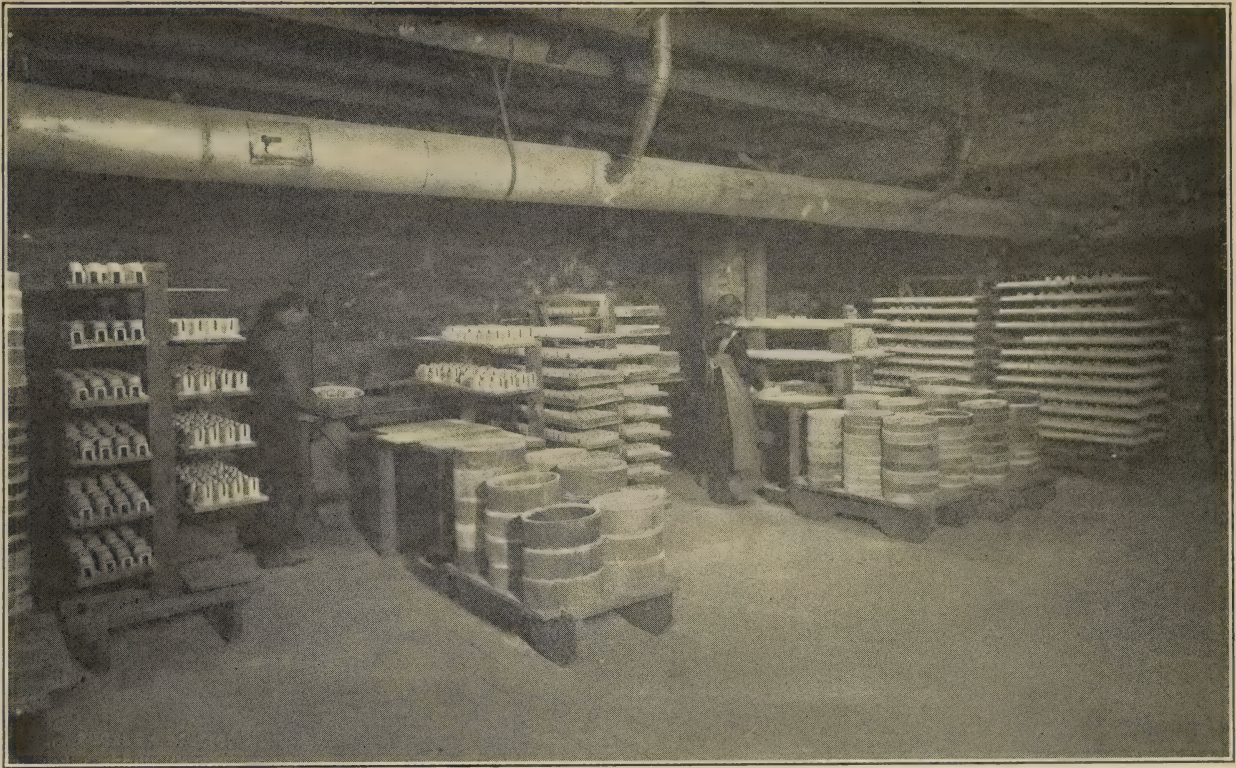

FIG. 4.—Loading dock where ware is placed in saggers. Racks fo ware are moved from the Cleaning Department to the loading dock by means of a lift truck. Saggers are piled on skids and also moved by lift truck. When saggers are filled they are placed on a belt conveyor which delivers them, without further handling, into the kiln being loaded. The man at the left is just placing a sagger on the belt conveyor.

tip over the green pieces or cause them to chip one another. Several manufacturers of conveying apparatus worked on this problem in conjunction with our engineers. None would guarantee the successful operation of the equipment so it was necessary that our engineers take full responsibility for the design finally adopted. Experience since has justified our decision.

The main belt conveyor is 14 in. wide and 180 ft. long, and extends the full length of the Kiln Department past the six kilns. It is placed about 6 ft. above the floor, or 3 ft. above the kiln floor and is located about 8 ft. from the doors of the kilns. Opposite the door of each kiln is a removable section wide enough to permit the insertion at right angles of a short section of belt conveyor driven by a separate motor. This cross conveyor unit carries at one end two rollers which, when clamped into the place where the section of the main conveyor is removed, depresses the main belt sufficiently to provide clearance for the cross belt to fit in place at the same level as the main conveyor belt. Saggers traveling on the main belt strike the section of cross belt traveling at right angles, rotate slowly as the cross belt secures traction and gradually alter their direction until they are moving smoothly at right angles into the kiln. Saggers being transferred from the main conveyor into the kiln on the cross conveyor are shown in Fig. 5. Both conveyors move at the rate of 24 ft. per minute.

The cross conveyor extends well through the kiln door and delivers the saggers onto a steel bench where several can be accumulated if the kiln loader is not ready to stack them. The loader is in telephonic communication with the loading dock so that he can direct the class of ware being placed to suit the position in the kiln where he is working. The cross conveyor is mounted on two large wheels and can readily be transferred from kiln to kiln. It takes two men about $^1/_2$ hour to change the cross conveyor from one kiln to another.

Unloading of Kilns

The belt conveyor also effects a considerable saving in unloading kilns, the under or return side of the belt being used for this purpose. The fired ware not being so fragile, a portable section of gravity roller conveyor, instead of belt conveyor, is used to extend from the inside of the kiln to the main conveyor. This has a slight pitch and is provided with a curved section at its lower end, made with rollers of gradually reduced diameter so that saggers of fired ware are deposited on the main belt without undue jarring, as shown in Fig. 6. Due to hard particles of wad clay on the bottoms of the saggers and the fact that many saggers are cracked or broken when removed from the bung, it has been found necessary for the kiln unloader to place each sagger of fired ware on a wooden pallet before start-

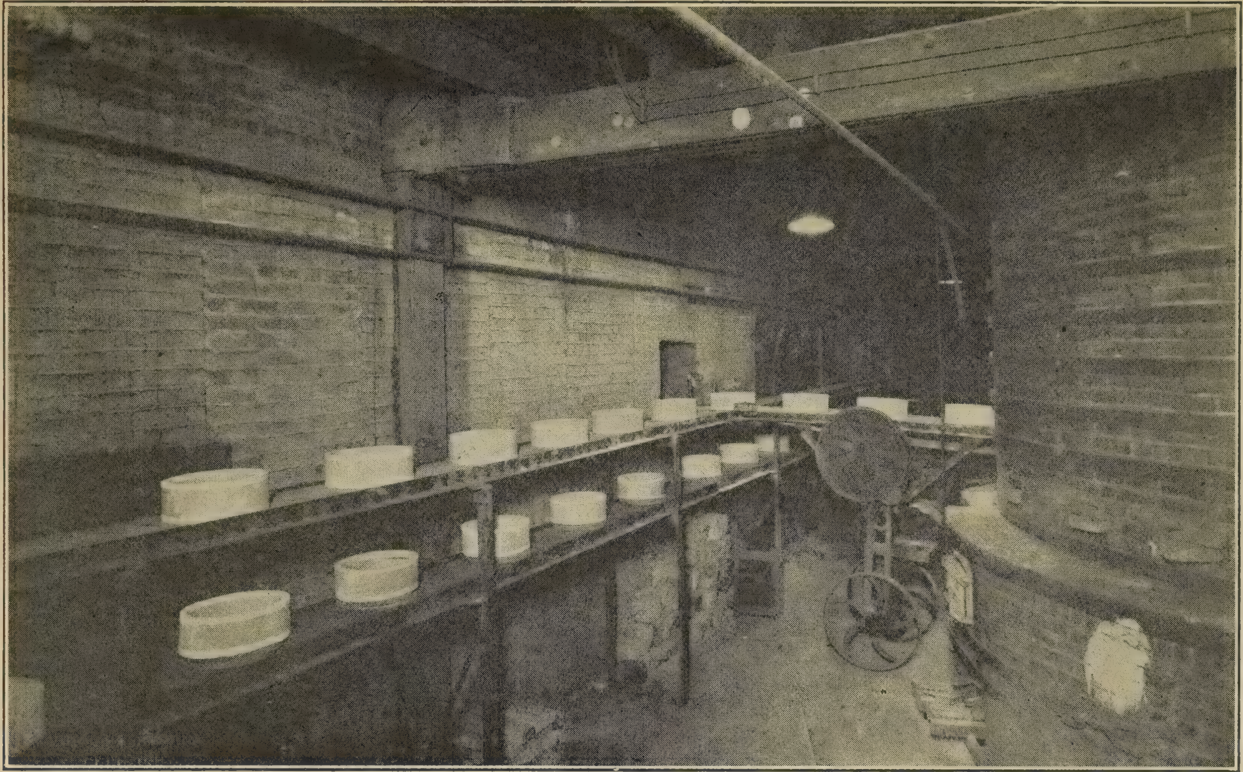

FIG. 5.—View of the main conveyor showing saggers being loaded and unloaded. The saggers on the upper belt are turned at right angles when they reach the cross conveyor shown in the foreground and are transferred into the kiln. Cross conveyor is portable and can be easily moved from one kiln to another. Saggers of green ware make the turn from the main conveyor belt to the cross conveyor belt without objectionable jarring.

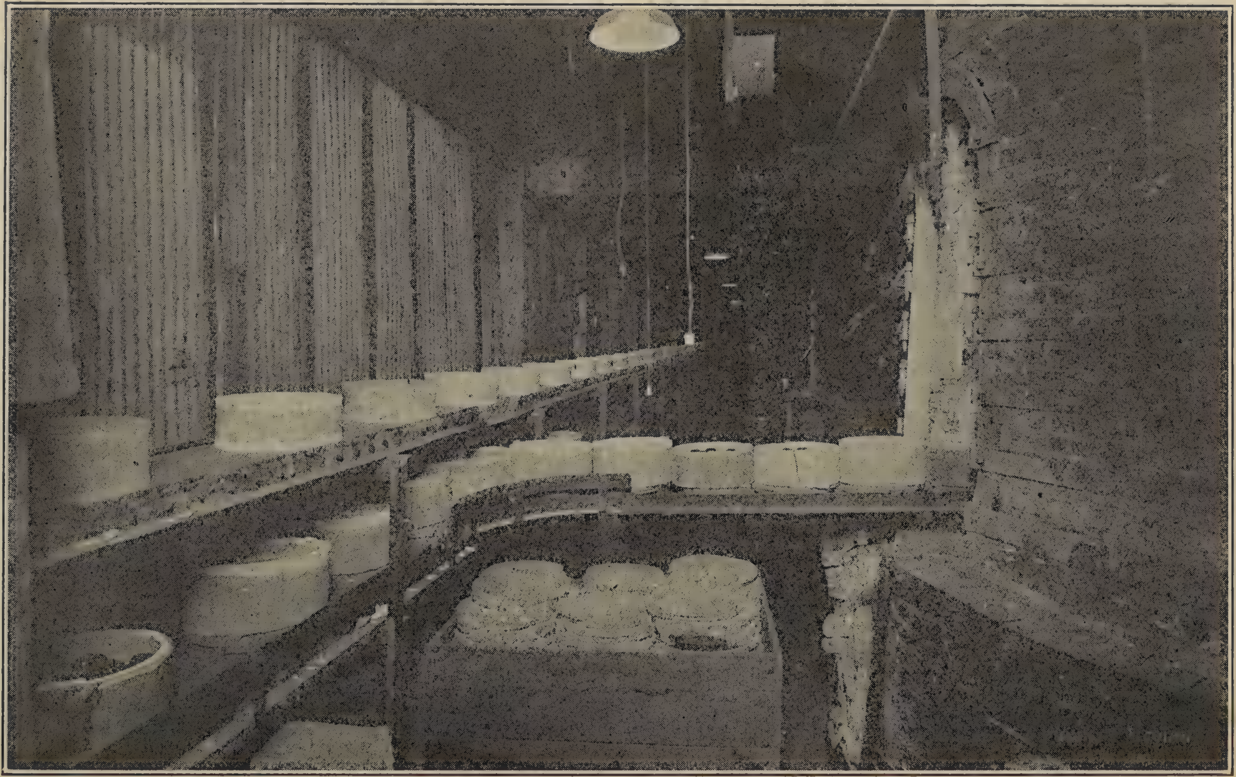

FIG. 6.—Unloading a kiln. The section of portable gravity conveyor carries the saggers of fired ware from the kiln to the main belt conveyor which delivers them into the Inspection Department. The upper belt of the main conveyor shows saggers of green ware passing onto the kiln being loaded.

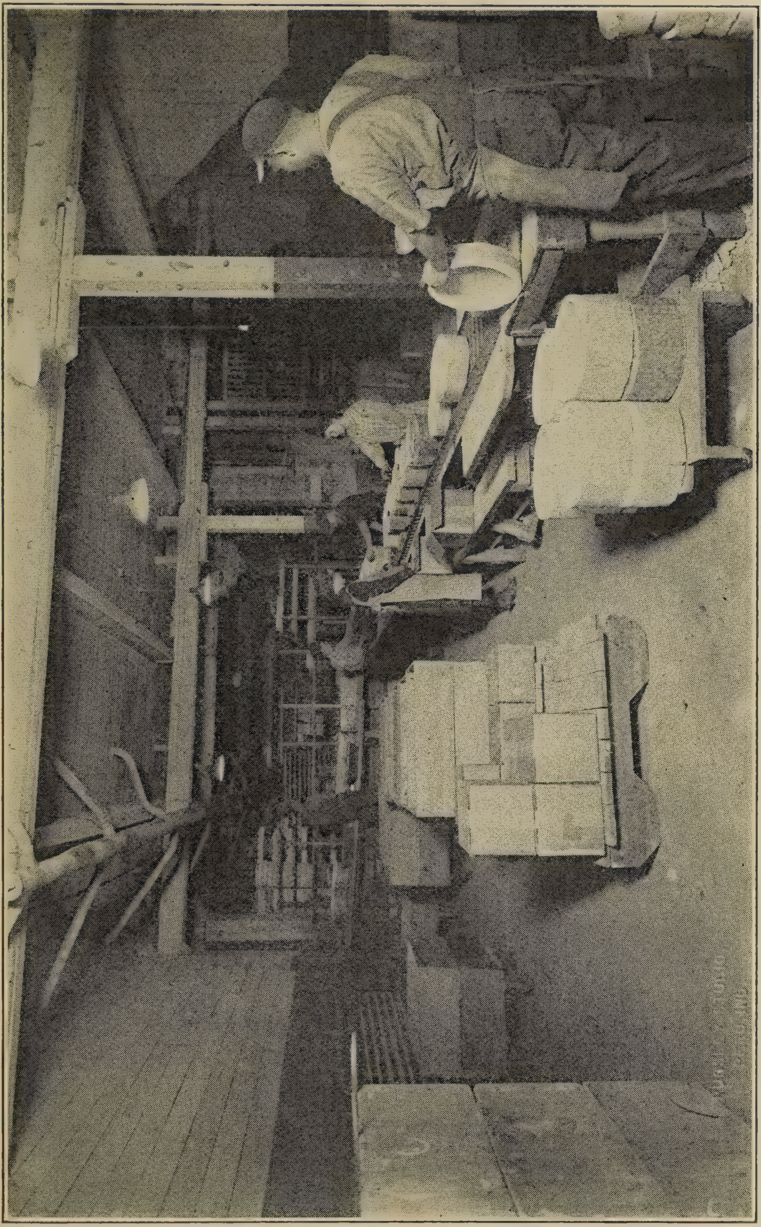

FIG. 7.—View of the Inspection Department. Saggers of fired ware are delivered by the belt conveyors onto gravity conveyor extending through the inspection room. Inspectors on either side of the conveyor remove the pieces, inspect them and place them in skid frames or pack them directly in cartons. The man at the end of the conveyor removes the saggers and pallets and delivers them back to the loading dock and the kilns to be used over again immediately.

ing it along on the gravity rollers as otherwise too great a pitch was required to make certain that it would keep in motion, not to mention the objectionable jarring if it struck the preceding sagger.

Inspection

Adjacent to the loading dock is located the unloading conveyor and Inspection Department. At this point the unloading belt is depressed by means of a roller and a curved section of gravity conveyor inserted so that the saggers of fired ware are diverted from the main belt and are turned at right angles into the Inspection Department where another similar turn brings them out on the inspection section of the conveyor as shown in Fig. 7. Inspectors stand on either side of this conveyor and remove the ware from the saggers, inspect it and place it in skid frames or cartons near at hand. The empty sagger goes on to the end of the conveyor where it is taken off and piled on skids with others of the same size. The pallet is thrown in a skid frame which when full is taken by means of a lift truck back to the kiln being unloaded. Whenever a skid of saggers is loaded it is taken by a lift truck to the loading dock and placed at the end of the bench where the same size saggers are being used.

The finished ware in skid frames is moved by lift truck to the Stores Department where it is stored in the same frames, making it easy to move it again to the Shipping Department by lift truck when shipment is to be made.

Economies Affected

Two men in a kiln, one to stack saggers in bungs, and the other to assist and put on wads, load a kiln in 9 hours or less. Three or four placers, depending on the class of ware, will load enough saggers for one kiln in 9 hours. By the old methods a gang of 8 to 10 men was required working both night and day—a total of 20 hours—to place ware and load a kiln. The new method therefore requires a total average of about 50 labor hours as against about 180 for the old. In addition, this makes it always possible to load a kiln every day and start firing the same night, resulting in an increase in the number of kilns fired per month, as well as reducing the cost of loading.

A saving of labor is made in unloading kilns, though a direct comparison is difficult. One man unloads a kiln in a 9-hour day and one man is required to handle the empty saggers, pallets, etc. It usually takes about four inspectors to take the ware from the saggers and inspect it. Under the old method whereby each sagger was carried out of the kiln by hand, dumped in a tote box and later rehandled when inspected, it required a gang of 5 men working night and day, a total of 20 hours to unload a kiln. There was also more breakage due to "pouring" the ware from saggers into tote boxes, which is eliminated by the new method. The rehandling by the inspectors is partly saved, but not entirely, as under the new method each piece is handled individually by an inspector, but the loss in breakage is greatly reduced. The use of a lift truck is also considerably more economical than two men carrying a tote box of the finished ware to the Stores Department.

The savings throughout the plant by the use of skids and racks with lift trucks is hard to estimate but appears well worth while. In conclusion, it can be said that the displacement of two men by the use of the above equipment would pay for the interest and depreciation on its cost. It can easily be shown to save the time of at least 10 men, to say nothing of reducing losses of heat in the drying rooms, losses of ware—both green and fired—in transit, and last but by no means least, the increase in the capacity of the plant without the addition of any productive equipment.

AN EXPERIMENT IN ELECTRIC SMELTING GLASS ENAMEL[1]

By E. E. Geisinger

ABSTRACT

Operating economies will require smelting of enamel frits in electric furnaces. A refractory enamel containing high content of metallic oxides was smelted in a combination arc and carbon resistor furnace, obtaining complete fusion without reduction of the oxides or change in character of the enamel.

Introduction

The stimulus to carry out the experiment of smelting glass enamel by electric energy rather than by oil or gas, as is the present practice, was found in the many estimates and predictions that the oil and natural gas shortage will be very acute not many years distant. The deserving place of the electric enamel furnace is rapidly being recognized, and a high temperature electric smelting furnace is just a step ahead. The success of the full carbon arc cylindrical type rotating furnace and of the smothered arc rocking furnace is well established in the non-ferrous alloy foundry industry, and they also are successful in the steel casting foundry. It may not be so far distant when the whole enameling plant energy will, economically, be electricity, hence the importance of knowing the fundamental results of enamel smelting by electric energy.

Conditions of Smelting Electrically

The Furnace Used.—The temperature requirement of approximately 2500°F makes any type of metal resistor furnace quite impossible, so a study was made of the different types of commercial arc, smothered arc, and combinations of these two types. When operated most economically, the atmosphere of these furnaces would be reducing, which condition is not correct for the smelting of any glass enamel and especially those containing metallic oxides. It is possible to run a smothered arc furnace neutral to slightly oxidizing, however, at the expense of an excessive consumption of the granular carbon resistor. The General Electric Company are building furnaces of the carbon arc and granular resistor type, in which the heat is transmitted to the bath partly through the trough refractories, but mostly by radiant reflection from the arch. This type of furnace would be more free from electrode residue dropping into the enamel bath.

Through the courtesy of the General Electric Company, and the kind help of Messrs. Lockwood, Lips and Keene of that company, arrangement was made to carry out the tests of smelting on April 14 and 15, 1920. The glass used was a blue-black enamel containing manganese, nickel and cobalt. This enamel was selected not only because of its high metallic oxide content that would rapidly show the effect of reducing atmosphere, but also because a high temperature is required to melt it properly. It is essentially a ground coat enamel.

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[1] Read before the Enamels Division, St. Louis meeting, Feb. 28, 1922.

The furnace used was small but identical in essentials to the large two-ton size. It had two large vertical electrodes descending into a granular resistance trough, which circled the 9″ x 9″ hearth in the center of the furnace. A sketch of the fundamentals of this furnace is shown in Fig. 1. This furnace would very readily receive an eight-inch high crucible, the size used in these tests. The glass used was a blue-black enamel containing manganese, nickel and cobalt.

Operation and Results.—In the first smelting experiment, the furnace was running on a load of 450 amperes at 60 volts, and registering a temperature of 1400°C or 2652°F. Carbon monoxide could be seen burning out of the cracks and openings of the furnace, but no attempt was made to obviate this. A 400-gram charge of the raw batch was introduced. At the end of 5 minutes it had gone down considerably, and was bubbling vigorously. At the end of 12 minutes, the glass was liquid and quiet. It was then poured into cold water as is the usual practice.

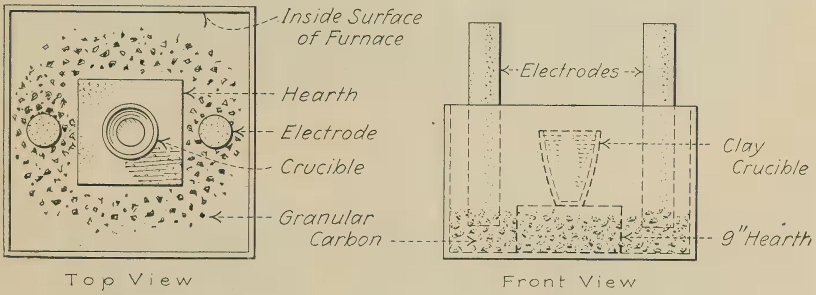

FIG. 1.

The liquid enamel was perfectly smooth, and free from unmelted pigments. The frit was black, sharp and glossy, and appeared identical to a gas or oil smelted enamel of the same formula.

A second test was run the following day. The furnace was heating up from 8 until 11 A.M., pulling anywhere from 350 amperes at 55 volts to 450 amperes at 60 volts and had attained by 11 A.M. 1250°C or 2272°F. A 600-gram charge was made at this temperature, although we knew that the furnace was not hot enough to properly melt the batch. This gave us an opportunity to note the effect of a long time period under these conditions. At the end of one hour and 10 minutes, the batch was quiet and the enamel was poured.

This batch appeared just a little undersmelted and contained a little unmelted material. The frit was vitreous, black and glossy, being all right in every visible respect. It would string out to a good, smooth and resilient thread.

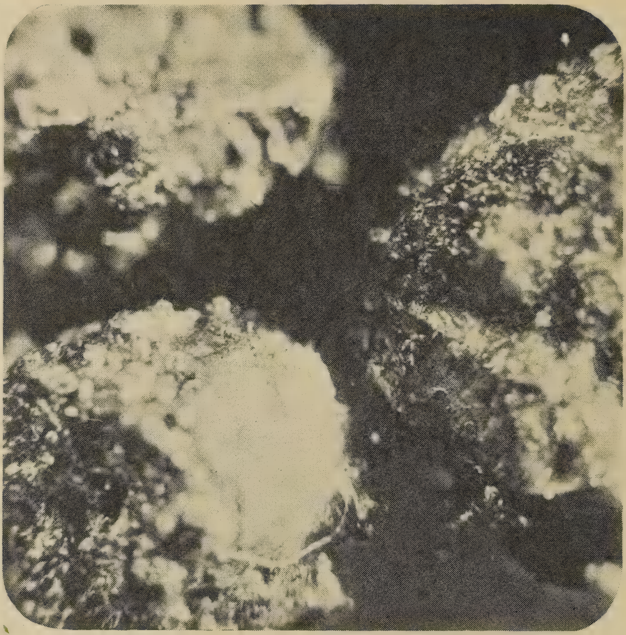

FIG. 2.—Nickel and cobalt globules. Mag. × 50. None of these batches were stirred. Heat seems to be the main essential, and the electric furnace had plenty of it. A bulk of the frit smelted electrically is shown in Fig. 3.

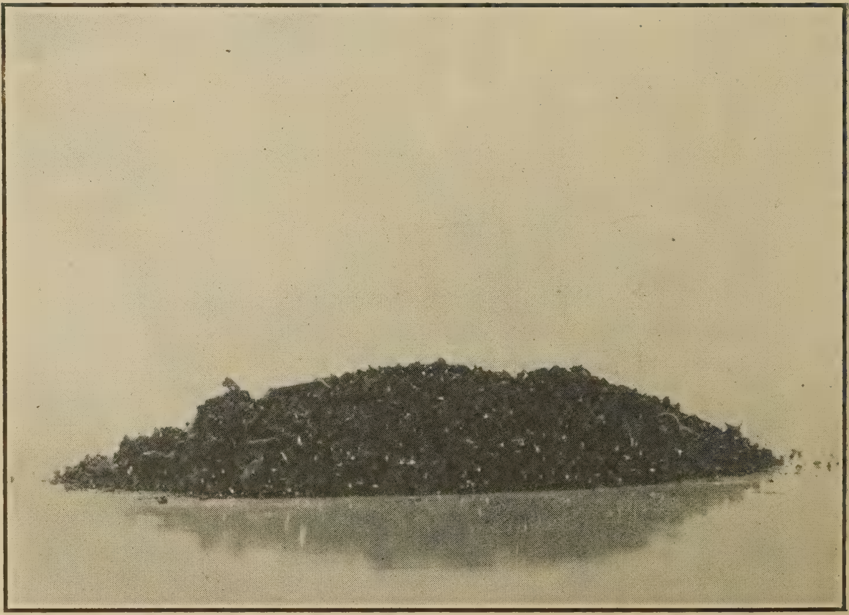

FIG. 3.—Electric smelted enamel frit.

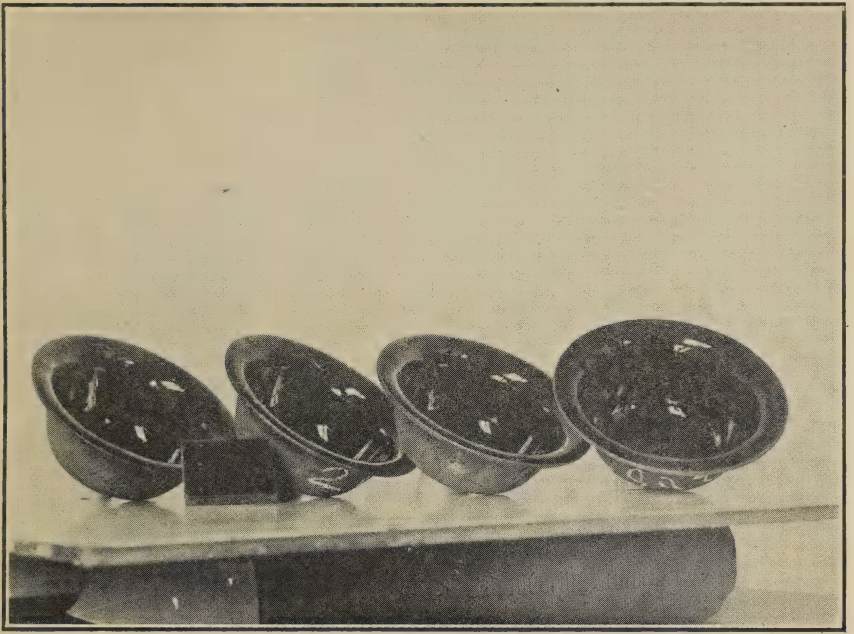

FIG. 4.—Work covered with electric smelted enamel.

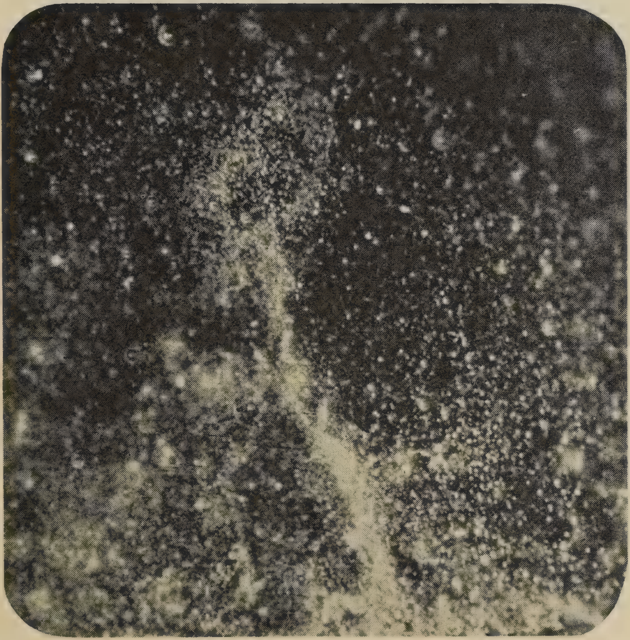

FIG. 5.—Top surface view of electric smelted enamel. Mag. × 75.

Examination for Evidence of Reduction

These two yields of frit were combined, totalling 650 grams of electrically smelted enamel. The crúcibles were taken to Rochester for examination, along with the frit.

The crucibles were carefully cracked to pieces and the glass residue in the bottoms examined for reduced metals or ummelted material. No evidence of reduction could be found. The glass in the bottom of the crucibles appeared just as solid and the same in every respect as that of oil smelted enamel. Every piece of the 650 grams of frit was combed over and examined, and only three small globules of metallic substance were found.

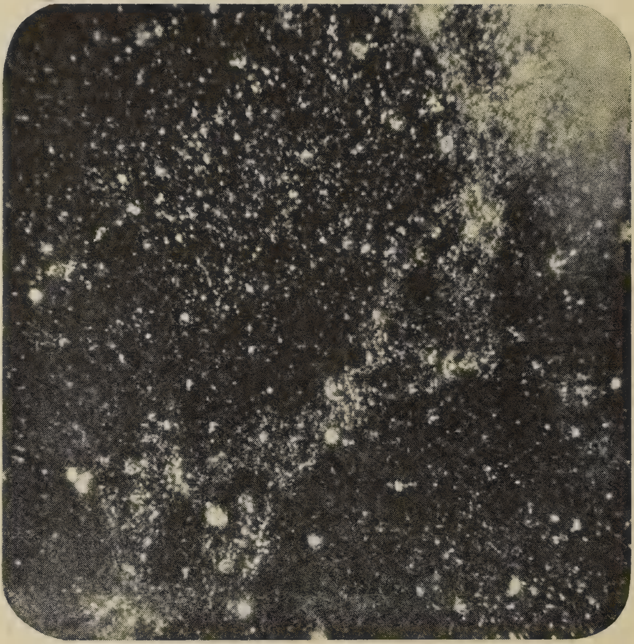

FIG. 6.—Surface of oil smelted enamel. Mag. × 75.

The microphoto of these three globules is shown in Fig. 2.

These pieces were found to be essentially of nickel and cobalt metal. This proved that some reduction had taken place, but it seemed almost impossible for this not to have happened during the second long time period. It was a great surprise to see the ineffectiveness of the furnace gases upon this enamel. A portion of saltpetre was in the batch as in most all enamels of this type, which, of course, inhibited or counteracted the reducing effect of the carbon monoxide in the furnace.

Application Properties of Electric Smelted Enamel on Steel

The last step in the experiment was to apply the enamel to steel and see if the properties had been materially altered. Four test cups were covered and one small rectangular test piece, which was to be used for microscopic examination. The enamel melted and finished at the same heat and time range as oil or gas smelted enamel. Samples of oil smelted enamel of this formula were applied to ware and fired right beside the electric smelted enamel for comparison. Fig. 4 shows the work covered with the electric smelted enamel. Fig. 5 pictures the top surface of the electric smelted enamel and Fig. 6 shows the top of the same enamel smelted with oil. Both microphotos are magnified 75 times. The four test cups covered with electric smelted enamel were tested electrically at 700 volts, and withstood this test perfectly. A higher voltage was not tried. A slight surface porosity or pitting can be noticed in the electric melted enamel.

It appears logical to conclude from the results of this small experiment that there is a possibility of smelting enamels electrically, when the balance of the smelting cost swings far enough in favor of electric energy as the heat source.

THE PFAUDLER CO.
ROCHESTER, N. Y.

THE ADAPTABILITY OF THE GAS-FIRED COMPARTMENT KILN FOR THE BURNING OF CLAY PRODUCTS

By W. D. Richardson

Introduction

The most notable development in the clay industries of America in the past decade, especially in the latter half of it, is the increased attention given to fuel saving and the increased number of installations of the continuous, regenerative kiln. This has been due to the depletion of natural gas and the increase in the price of coal and fuel oil.

The burning of claywares on cars while they are being progressed through a tunnel, every cross section or vertical zone of which is constantly kept at the same temperature, is an ideal method that has been the dream of clayworkers for no one knows how long, at any rate long before my entrance into the industry. In fact, when I first began the making of dry-pressed face brick, thirty-five years ago, of the half-dozen or so manufacturers who were then making a good quality of dry-pressed brick, one of them was burning his product in a tunnel kiln of his own invention. From that time I have known or been associated with three other men who have designed and patented tunnel kilns for burning brick. The first man, above mentioned, is the only one of these who was able to secure the capital for trying out his invention. He certainly put out some excellent brick but, as his plant was well fenced in and no visitors allowed, we can only guess why the business turned out to be a failure.

These remarks are not made to discredit the tunnel kiln, since these early inventors attacked the hardest problem, even for the tunnel kiln of today, that of burning the heavier and cruder products of the common, impure clays. The tunnel kiln, like every improvement in manufacturing processes, has been evolved from repeated failures. Undoubtedly further improvement in the tunnel kiln will make it most advantageous under some conditions and for some products.

It should be noted, however, that comparisons are made with the old periodic kiln and not with the latest developed continuous kilns of other types.

I have had several years' experience in the operation of the compartment kilns and have given considerable thought to their improvement. It is true, my experience with the compartment kiln has been entirely in the burning of face brick and hollow building tile, but since producer gas has become such a practical fuel for ceramic and metallurgical operations the compartment kiln can easily be adapted to the burning of any kind of ware and has a wider range of usefulness, as we will attempt to show, than any other type of kiln.

The Compartment Kiln

It is understood that we mean by the compartment kiln a series of kilns, in juxtaposition, separated by a common wall and connected with each other by openings in the walls above or below the floor level, the kiln being in continuous operation, the air for combustion of fuel being heated by passing through compartments of the burnt ware back of the fire and the hot combusted gases passing through and preheating the compartments ahead of the fire. These kilns are sometimes built in a single row, but preferably in a double row, either in juxtaposition or separated. This continuous kiln was a later development of the Hoffman Ringofen or the annular continuous tunnel or double row of parallel tunnels connected at both ends, now often built in this country as a single tunnel fired from the top and through doorways. This latter might properly be called the tunnel kiln and the so-called tunnel kiln be called the continuous car kiln or the continuous stationary-fire kiln.

The compartment kiln when direct-fired with coal from the top was introduced into this country many years ago, one form coming from Scotland and one from Germany. When properly built and operated, it was a good kiln for brick, giving better results than the annular or continuous tunnel kiln, but costing more to build and keep in repair. This compartment kiln was fired with coal from the top into specially constructed fire boxes or combustion bags, on one or both sides of the compartment. The progress of the burning was rather slow, especially if high temperatures were required, since the combustion bags became more or less filled with ashes by the time the burning was finished and thus the flow of air to the fires through so many of these bags was retarded.

Importance of Producer Gas as Fuel

The continuous compartment kiln could not have been presented today for the burning of pottery and refractories had it not been for the successful introduction of producer gas. Producer gas has made it practicable to design a compartment kiln for any ceramic product and makes this type of kiln deserving of consideration in any branch of the clay industry.

Producer gas can be conducted to any part of a compartment and in any quantity and its combustion controlled, so that any desired temperature may be reached quickly and oxidizing or reducing conditions maintained at will. As no ash is deposited on the ware and no flame need strike it, no protection for the ware is required.

Gas producers have been and are still made and sold that give serious trouble. Such producers have retarded a more extended use of producer gas, notwithstanding the fact that the making of good combustible gas from any fuel, wood, peat, lignite, bituminous or anthracite coal or oil, is a simple operation, and, when understood and with the proper equipment, involves very little labor or attention. Lignite and many bituminous coals cause much trouble in many producers from the formation of clinker, and some very elaborate mechanical producers can only be operated successfully on a coal giving an ash that slags at a high temperature. There need be no trouble in making good gas from any old coal, since we have learned to prevent the formation of clinker. To elucidate the gas producer problem would take us beyond the limits and purpose of this paper, which is to show that the compartment kiln, fired with producer gas, has a wide range of usefulness and in many cases is the most practical kiln.

Experience with Gas-Fired Compartment Kiln

The kilns that the writer has operated, in the burning of high-grade face brick, have compartments of such size that they could be filled with one gang of setters (two tossers and two setters) in two working days. This means that a compartment must be burned every two days. The compartments were two-side firing, 18 feet wide, 43 feet long and 10 feet high, from floor to top of crown inside. When the burning of a compartment was finished, the compartment next ahead of the fire would be red-hot to the bottom and the second compartment ahead of the fire be incandescent half way to the floor and sometimes to the floor. The burners often finished in 36 hours and sometimes, with the more refractory brick, burning to cone 10, in 24 hours' firing. The burning was always ahead of the setting and emptying and the burners and producer men regularly were not on the job from Sunday morning to Monday morning.

During all my experience with the compartment kiln we were burning the same brick also by direct firing in periodic kilns, so that our yearly tabulations showed accurately the comparative consumption of coal in the two forms of kilns. The producer-gas-fired compartment kiln has required less than half of the amount of coal consumed in the periodic kilns. Moreover, the continuous kiln was much more uniform in results, since its operation is more systematic and under better control.

Adaptability of Compartment Kiln to Pottery

Since, in the burning of pottery wares, uniform results and quick operation are desirable, the compartments should not be too large, though they should probably be larger than most pottery men have been accustomed to. In any case, the compartment should be filled in one working day and burned in 24 hours' firing.

If it is desired to cool the compartments more rapidly, portable crowns may be used. Such crowns are entirely practical and have the advantage of costing less for repairs than the permanent crown.

One reason that many pottery manufacturers hesitate to install a compartment kiln, or continuous kiln of any kind, even in a new factory, is that it means a somewhat different method of handling the wares from the kiln. The solid row of compartments would block a direct passage from each kiln to the next department, requiring the ware from the bisque kilns being moved a farther distance to get them to the bisque warehouse or dipping room, and the ware from the glost kilns being moved a farther distance to the warehouse or packing room. This, however, does not mean any greater cost of handling, but a different system. Instead of the ware being carried by the kiln drawers to the next department, it must be placed by them on trucks or cars or continuous conveyors. If the kiln is built in a single row, with doors in both ends of each compartment as would generally be the case in a pottery, the conditions are most favorable for economic handling of wares, without conveyors.

Summary

The advantages of the continuous compartment kiln, gas-fired, are:

1. A saving of 60 to 70 per cent of the fuel used in periodic kilns under the best conditions.

2. A more compact kiln plant, less waste of space in the factory.

3. No coal to be distributed around the plant and no ashes to be removed from around kilns. All the coal unloaded mechanically at one place and ashes removed mechanically.

4. More rapid firing, a larger quantity of fuel can be introduced and no fuel fired in a compartment until it is red-hot throughout. In the compartment kiln, with induced draft, rapid progress can be made and oxidizing conditions maintained and the heat from the combusted gases utilized to the fullest extent in preheating the wares in the compartments ahead of the fire. In a tunnel kiln, whether of the stationary fire or progressing fire type, the capacity of the kiln is limited, since a strong draft does not distribute the heat properly and a weak draft, to overcome this, produces reducing conditions that are sometimes undesirable.

5. Better control of the burning, as compared with the periodic kiln, because of regulation at will of the gas and air, enabling the burning process to be reduced to a system. No special skill required.

6. Greater uniformity of heat distribution—more uniform product.

7. Less cost for repairs than the periodic kiln and the advantage over the car tunnel kiln that repairs can be made without serious interruption of the operation of the kiln.

8. Less cost for operation per ton of ware burned.

9. The advantage over the tunnel kiln that a greater variety of ware, as to size and temperature required, can be burned. Greater flexibility and adaptability. Any compartment may be filled with either bisque or glost ware without interfering with the regular operation of the kiln. The firing may be hastened or slowed up, as desired.

10. No delays due to the sticking of cars or damage to cars or to failure of mechanical pusher.

11. Ware not subject to motion or vibration, as in the car tunnel kiln.

12. No cars to be repaired or replaced.

13. No change in the regular method of placing kilns, though the work is made easier, since the bungs are not as high as in the old type of kilns.

14. The lower height of the bungs and the absence of abrupt heating increase the life of the saggers.

15. The bisque suffers no harm owing to sudden and rapid cooling, as is often the case in tunnel car kiln.

16. The ware may be warmed up by means of pure heated air drawn from cooling chambers, thus making it impossible to sulphur the goods.

While it is true that no single type or form of kiln is the best for all products and conditions, yet it is a fact that, we believe, cannot be controverted, that the compartment, gas-fired continuous kiln has a wider range of practical utility than any other form of kiln.

TYPES OF GLAZES SUITABLE FOR DECORATIVE INLAY PROCESSES

By Frederick H. Rhead

ABSTRACT

A definition of the inlay process is given. Type of outlines and method of application are discussed. Glaze formulas in present use are noted, and general conditions necessary for the successful execution of this process are outlined.

Definition.—The term "Decorative inlay process" is applied to those decorations consisting of a design with a raised, sunken, or flat outline filled in with flat or slightly shaded coats of glaze, preferably colored matte.

It is a kind of cloisonné process with the difference that the outline is not a metallic wire, or strip, although copper, gold and silver wire have been used on the clay surface, and the spaces between the wires have been filled in with glazes.

This process has been used by the Chinese and Japanese potters, and is in general use among the European Art Potters. In this country it has been confined to the individual potter, some of the schools, and to some extent by the faience and tile manufacturers.

Two Essentials.—The two essentials are a suitable outline, and a type of glaze that will not readily flow over the outline, and mix or run into the surrounding glazes.

The Outline.—If a raised outline is desired, this may be incised in the mold resulting in a raised line on the ware, or it may be applied in slip form by means of a collapsible tube. When the latter process is used various colored outlines are possible in the same design.

When the outline is flat, underglaze black or any other color is practical. Pure manganese well ground is a most satisfactory outline. It is not dry in texture, and the colored glazes will not easily flow over the line.

An excised or sunken line is also very satisfactory. Curiously enough the glazes will not flow into the sunken line unless the glazes are much too heavily applied. If the decoration is being applied to a white or light-colored body, and a darker outline is desired, underglaze color can be rubbed or brushed into the excised line, and the color cleaned from the surface with a sponge.

It is very important that the outline should be clear and firm, and that all areas to be filled in are completely surrounded by the outline color, otherwise there is danger of the glaze flowing or breaking through. It is obvious that a readily flowing glaze is not suitable for this process, especially if an upright or curved surface is being decorated. While the glazes given will not flow readily on upright surfaces, care must be

TABLE I

TYPES OF GLAZE

	White Matte 03–01	White Matte 03–01	White Matte Cone 1–3	White 10–12 Matte	White Transparent 03–1	White Transparent Cone 1–3	White Transparent Cone 8–10	White Enamel Cone 03–01	White Cone 1–3	White Enamel Cone 9–11
White Lead......	200	225	52	..	330	185	310	355	..	..
Feldspar.........	110	55	24	500	160	55	240	220	225	435
Flint.............	35	90	..	125	175	35	225	165	165	125
Whiting..........	25	12	16	250	45	12	150	90	90	170
China Clay.......	35	26	20	250	8	..	50	..	5	175
Zinc.............	30	74	5	35	14	10	40	..	10	..
Cornwallstone....	85	..	24	..	..	55	240	..	..	..
Barium Carbonate	30	..	..	..	5	..	17	..	..	..
Tin Oxide........	25	..	..	..	..	..	10	175	180	50
Ground Flint Glass	..	..	..	..	200	..	60	..	..	85
Borax............	..	..	..	..	15	..	5	..	..	..

These formulas are for white base. The bases can be stained in the usual manner either with raw metallic oxides or with underglaze colors.

taken not to apply them too heavily, or to over-fire the completed work. Preliminary tests should be made for the character of the outline, thickness of glaze coat, and firing temperature. When determining the firing temperature a set of cones should be placed as near to the ware as possible.

Medium for Glazes.—A solution of about ten per cent of gum tragacanth is mixed into a glaze of creamy consistency. The glaze should be brushed through a forty or sixty mesh sieve at least twice after it has been mixed with the gum. The medium should be added to the glaze at the time it is to be used. An average painting mixture would be about equal parts gum solution and glaze. The exact consistency of the glaze will depend on the porosity of the ware. More gum, and a thicker consistency is necessary on a very porous body. If the glaze dries too quickly while it is being applied more gum should be added. If the glaze does not settle, or dry, or if it flows outside the outline, the glaze is either too thin, or a too heavy coat is being applied. Only freshly mixed gum may be used.

Preparing the Gum.—The flake or powdered gum tragacanth is added to hot water and allowed to dissolve for about twenty-four hours. It is then thoroughly stirred and brushed twice through a twenty or forty mesh sieve. Only enough gum should be mixed for a supply to last about a week. The gum will keep longer if from one to two per cent of salt is added when the mixture is first put through the sieve.

Brushes.—For small areas Nos. one, two, three and four ox hair writers' or sable brushes which have had the outer bristles cut away are excellent. A No. five and a No. three sable water color brush cut to half the size at the ferrule make very useful tools. Do not cut the points of the brushes.

Application, or Glazing Process.—It is assumed that the design is broken up into average areas of one square inch or thereabouts, and that each area is entirely surrounded by an outline, either raised, flat, or sunken. Some glazes may be juxtaposed without any outline, but it is advisable not to attempt this without considerable experience with the glazes being used.

The glaze is poured into a small crock, and the brush moistened just enough to allow it to be damp and springy. It is then dipped into the glaze at the point, and allowed to take up just enough glaze for a globule large enough to drop off the end of the brush. The brush should not be dipped entirely, or stirred into the glaze. The glaze is really picked up by the end of the bristles of the brush. The process is about as follows:

1. The brush is dipped into water and wiped over a damp flat sponge to take out surplus water.

2. The brush is pointed into the glaze two or three times until it has picked up a fair size globule of glaze.

3. This globule is immediately applied to the surface and the process repeated before the first application becomes dry. The entire applied area should still be moist by the time the surface is covered. If one portion begins to dry before the wash is completed, there is not enough gum in the glaze, or the consistency is too thin. An average consistency for a porous body would test out at 1800 with a heavy liquid hydrometer.

If a vitrified body is being decorated, two or three coats of glaze may be necessary, each coat being allowed to become fairly dry, or quite dry before a further coat is applied.

This process like the various other decorative methods is rather difficult to describe intelligibly without illustration or demonstration. There are various points in regard to technique which are adaptable to individual or personal treatments, but there are certain practical essentials which must be recognized. In the order of the process, these essentials are:

First: A clear outline of some character.

Second: The correct consistency for the glaze.

Third: Brushes as described. It may be noted that the ox hair writers' and the cut sable brushes are rather difficult to manipulate at first, and the decorator may try to use the ordinary water color brush, or a brush of larger type. But the colors are floated and not painted or brushed over the surface. The brushes specified are suggested because they have been found suitable after many experiments with various types.

Fourth: The correct thickness of the coat of glaze. When a flat surface is being decorated there is little danger of the glazes running or flowing, but when a vase or upright surface is being glazed there is bound to be some movement of the surface if the glaze is applied too heavily. After some experience, the decorator can allow for a certain flow. The upper portion of the applied area may be a little heavier than the lower portion. This slight variation in the thickness of the coat will be adjusted by the movement of the glaze during-firing.

Fifth: Care not to over-fire.

Remarks.—In general, this process is more suitable for individual work than for regular factory production. Except where the designs are simple and consisting of not more than two or three colors, the process is rather intricate and laborious. But very beautiful effects are possible, and it is an invaluable process for the studio potter, and for high-class commercial art work. As is the case with most of the decorative processes, important work should not be attempted until trials and tests have been made in connection with bodies, glazes, outlines, technique and firing conditions.

RELATION OF COMPOSITION TO THERMAL SHOCK IN STEEL ENAMELS[1]

By B. T. Sweely

Testing enameled ware for resistance to sudden changes in temperature is rather a broad field, and has been well covered by a number of investigators of this subject. The writer's purpose is not to present a new test nor to draw any very definite conclusions, but I should like to bring to the attention of the people interested the results of some of our experimental work with a few different compositions when subjected to sharp temperature changes.

Any study of the resistance of ware to thermal shock must take into consideration the ground coat as well as the finish coat and the relation of their physical properties to one another. A good ground well burned in is very difficult to separate from the steel, the adhesion of the enamel to metal being well above the strength of ground coat glass itself, as is evidenced by the knocking off of any good ground where a coat of glass remains clinging to the steel. It seems probable, therefore, that failure due to sudden change in temperature is caused by separation of the finish enamel from ground, or failure of one glass or the other to withstand the stresses set up by the sudden temperature change. Under these conditions the elasticity and tensile strength of the glasses play an important part and should be as high as possible for best results.

The stress set up in a piece of enameled ware by a sudden change in temperature can only be due to differences in the rate of expansion or contraction of the steel and enamels, and is, therefore, the primary cause of failure. It must be borne in mind that in suddenly cooling a hot piece of ware, especially what is known as three coat, a very appreciable lag in temperature drop is experienced between enamel and steel, as when the piece is plunged in cold water. In this case the enamel on the outer surface is instantly chilled and contracts, but due to the poor heat conductivity of the enamel itself, the outer layer of enamel may be at the water temperature, while the steel and first coat are still very hot. The stress set up under this condition is often sufficient to exceed the strength of the glass, and spalling, and chipping will result. From the above considerations, therefore, it seems quite probable that even though the coefficients of expansion of enamels and steel were exactly the same, failure might still result if the enamels were applied in a rather heavy coat, the latter having been well borne out by the practical experience of the enamel industry, the work of Shaw and others who have found resistance to thermal shock greatest when the enamels are applied in thin coats.

Again considering the coefficients of enamels and steel, it would seem that if the coefficient of the finish enamel was lower than that of the steel and first coat, the stress set for any given temperature change should be smaller, and the probability of failure decreased. Further, since the adhesion of ground to steel as mentioned is very much above the tensile strength of the glass itself, it would seem logical to increase the coefficient of expansion of the ground coat as much as possible, in order to have as much contraction as possible over the temperature interval occasioned by the loss of heat through the cover enamel when the piece is immersed in the cooling medium. Under these conditions, cover enamel and first coat should contract at a rate more nearly coincident and the stress set up by any sudden temperature change be decreased, and, other limiting factors not interfering, it should be possible to develop enamels so adapted to one another that the resistance of the ware to thermal shock could be materially increased.

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[1] Read before the Enamels Division, St. Louis meeting, Feb. 28, 1922.

With the above points in mind, two first coats were made up of the following composition and coated with the white enamel formula given. The compositions used were as follows:

No. 1 FIRST COAT MELTED WEIGHTS

Feldspar	34.6
B_2O_3	13.85
Na_2O	15.50
Fluorspar	7.5
SiO_2	25.4
MnO_2	2.0
NiO	.5
CoO	.42
Cubical Coeff.	318×10^{-7}

No. 2 FIRST COAT MELTED WEIGHTS

Feldspar	55
B_2O_3	5
Kryolith	12
Na_2O	10
Fluorspar	7.5
BaO	10
CoO	.5
Cubical Coeff.	432×10^{-7}

WHITE ENAMEL MELTED WEIGHTS

Feldspar	22.2
B_2O_3	9.8
Na_2O	8.23
Kryolith	18.00
Fluorspar	7.86
Zinc Oxide	2.00
SiO_2	31.90
Cubical Coeff.	334×10^{-7}

This white enamel used on No. 1 first coat produces a ware of about the average resistance to temperature change. A piece of this ware placed over a Bunsen burner, heated to red heat and quenched with water will spall off in one or two trials. The same white enamel applied to the No. 2 first coat and tested as above will withstand the test five or six times repeated without chipping or spalling off.

Since the only known difference in the trials tested was in the ground coat used, the increased resistance to thermal shock is probably due to the higher coefficient of expansion of the No. 2 ground.

We are continuing our work on this phase of the problem and hope to present further data at a future date. The writer draws no conclusions and makes no recommendations but presents the data for what they may be worth to those interested, as the results so far secured seem favorable.

Ceramic Laboratories
Coonley Manufacturing Co.
Cicero, Illinois

CORRECTION

This Jour., **5**, 209 (1922).

In the Abstract for "The Testing of Silica Brick" by K. H. Endell. Line 2, read "hollow carbon rod" for "hollow carborundum rod."

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Vol. 5 **June, 1922** **No. 6**

ORIGINAL PAPERS

DATA ON THE OPERATION OF A CONTINUOUS TUNNEL KILN AT THE PLANT OF THE A. C. SPARK PLUG COMPANY[1]

BY SAMUEL J. MCDOWELL AND PERRY D. HELSER

ABSTRACT

This kiln has total length of 75 feet and interior width of 2 feet 8 inches. Design is based upon the idea of firing small thin mass at a rapid rate, only 12 hours being required for the burning operation. The ware, spark plug porcelain insulators, is passed through in a single, unprotected, horizontal tier, being subjected to direct fire. The kiln is operated at cone 18 half down. City gas is used, with burner equipment which is a modified form of Surface Combustion.

The initial cost is low. The kiln is of simple construction, permitting rapid heating and cooling. Output depends upon ability of individual pieces of ware to safely absorb heat necessary for their vitrification. The process is patented.

Introduction

The data given in this paper has been obtained from tests and observations on the tunnel kiln installed at the plant of the A. C. Spark Plug Co., Flint, Michigan. It covers a period of over two years' successful operation, first at cone 16 and later at cone 18.

This kiln is used for firing spark plug porcelain insulators. It is probably unique for several reasons:

1. The kiln proper is but 60 feet long, with an additional wind tunnel of 15 feet, making a total length of 75 feet. The interior width is 2 feet 8 inches.
2. A high temperature is obtained for a kiln of such length.
3. The kiln is open or direct fired.

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[1] White Wares Division, St. Louis Meeting, Feb. 28, 1922.

4. The ware is passed through in a single horizontal tier subjected to direct fire, that is, not protected by saggers.

5. The ware is advanced continuously, in contrast to the type in which the ware progresses more or less intermittently.

6. The construction is simple. The cost of installation is, therefore, comparatively low. This simple construction allows the kiln to be brought to a maximum temperature in a minimum length of time without detrimental effects to the structure.

7. It is possible to closely control the composition of the kiln atmosphere, maintaining either oxidizing or reducing conditions.

8. The kiln, throughout its length, is supported on concrete arch construction. This permits access to the space under the cars at all times. It also prevents possible overheating of the steel framework of the cars.

Description of Kiln

Preheating Zone.—The preheating zone is lined entirely with high grade fire brick. The walls are built of fire-brick and Nonpareil insulating brick. The arch is built of a double rowlock of fire-brick with a covering of insulation brick.

Drop arches of fire-clay shapes act as baffles to force the hot combustion gases down around the ware as the preheating progresses.

Hot Zone.—The hot zone walls are built of silicon carbide brick, high grade fire brick, and Nonpareil insulating brick. The arch is similarly built of carborundum brick, high grade fire brick and insulating brick.

There are nine burner openings in each side. The burner orifices open into the kiln slightly above the level of the ware and at such an angle as to allow the flame to impinge upon the arch.

At the end of the hot zone is a soaking or retarding zone of similar side wall construction, but with hollow arch construction of carborundum blocks filled with Kieselguhr. These blocks form a drop arch immediately over the ware to prevent the hot gases from escaping toward the cooling end of the kiln.

Cooling Zone.—The cooling zone is composed of three sub zones: (1) *Muffle Cooling.*—The top of the muffle cooling zone is built of fire-clay shapes and corundum slabs, so arranged as to give a continuous air duct leading back and forth over the ware from an opening in the cool end of this sub zone to a stack in the hot end, where the hot air escapes.

(2) *Water Cooling.*—The walls and arch of the water cooling zone are built of second grade fire brick. Coils are placed immediately above the ware and water passes through them continuously.

(3) *Direct Air Cooling.*—This was not a part of the kiln as originally designed. However, the cars and ware came out too hot to comfortably

handle and a wind tunnel of 15 feet was added. The walls are built of brick and the top is constructed of sheet metal.

An air duct leads from a fan to two openings through the sheet metal top of the wind tunnel and near the exit end of the kiln. The air from this fan is prevented from entering the kiln proper by a flap which brushes on top of the ware.

A sand trough runs the entire length of the kiln on either side. It is built of angle iron and is bolted to the concrete through slotted holes to allow expansion.

Pusher.—The pushing mechanism consists of an endless chain extending six feet into the kiln under the center of the cars. The chain carries dogs four feet apart. Each of these dogs in turn engages the rear axle of the last car and pushes forward the entire train. The chain is propelled through various speed reducing mechanisms by a continuously operating 3 H.P. motor. The power actually required is 1 H.P. The speed reducing mechanism is so arranged as to permit control of the rate of travel through the kiln. This rate may be varied from a minimum of five hours to a maximum of thirty hours elapsed time for travel through the kiln.

Burner Equipment.—The burner equipment used is a modified application of the Surface Combustion low pressure system. In this system the air is supplied by a Root's positive pressure blower. The gas is reduced to atmospheric pressure by means of a regulator. The air and gas are then automatically mixed in any desired proportion. This explosive mixture is forced through the burner orifices and impinged upon the arch of the kiln.

Fuel.—The fuel used is artificial city gas. This is a mixture of coal gas and water gas enriched with oil to insure a product having a heating value of approximately 550 B.t.u. per cubic foot.

Burner equipment is on hand for the application of fuel oil, the possibilities of which we plan to thoroughly investigate.

Pyrometer Equipment.—The pyrometer equipment consists of two base metal couples in the preheating zone, three in the cooling zone, and three platinum couples in the hot zone. These couples are connected to an indicating pyrometer which is read and recorded every thirty minutes.

Figure 1 shows a car of ware entering the kiln.

Cars.—The cars are 4 feet in length and 2 feet 6 inches in width. Steel aprons attached to either side of the cars drag through the sand in the sand-seal trough and prevent the hot gases from coming into contact with the wheels and rails.

Refractory blocks are placed along the edges of the steel car frame, while in the center insulating brick are used. Additional refractory blocks cover the entire car.

The trays are 15″ x 16″ x 2″ outside dimensions and are approximately 1″ thick. They are composed of fire-clays and grog and are formed on a sagger press. The life of the trays is lengthened because of the fact that they carry only the weight of the ware in them.

In the event of firing ceramic ware of sufficient base area to stand unsupported, the trays might be dispensed with and the ware placed directly upon the car, thus eliminating the use of saggers or the like.

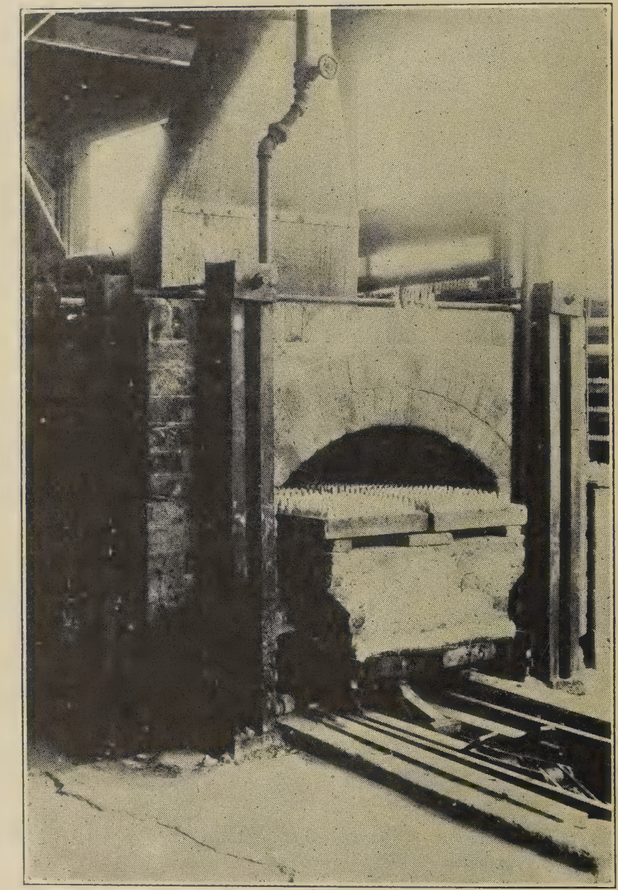

Fig. 1.

Ware.—The ware consists of one-fire, glazed porcelain spark plug insulators approximately $2^1/_2''$ in length by $^3/_4''$ in diameter. They are placed in the trays with unglazed shoulders touching.

Standard Conditions of Operation.—The kiln was put into operation in November, 1919, at a temperature of cone 16 touch. Later a change in body composition necessitated a temperature of cone 18 half down, and since that time the kiln has been operated at this latter temperature.

The kiln is operated on a twelve-hour schedule, that is, twelve hours are required for a car to pass from the entrance to the end of the kiln proper (60 feet), at which location access is gained to the ware. This speed means that the car advances through the kiln at the rate of one inch per minute.

Figure 2 shows a car of ware emerging from the wind tunnel.

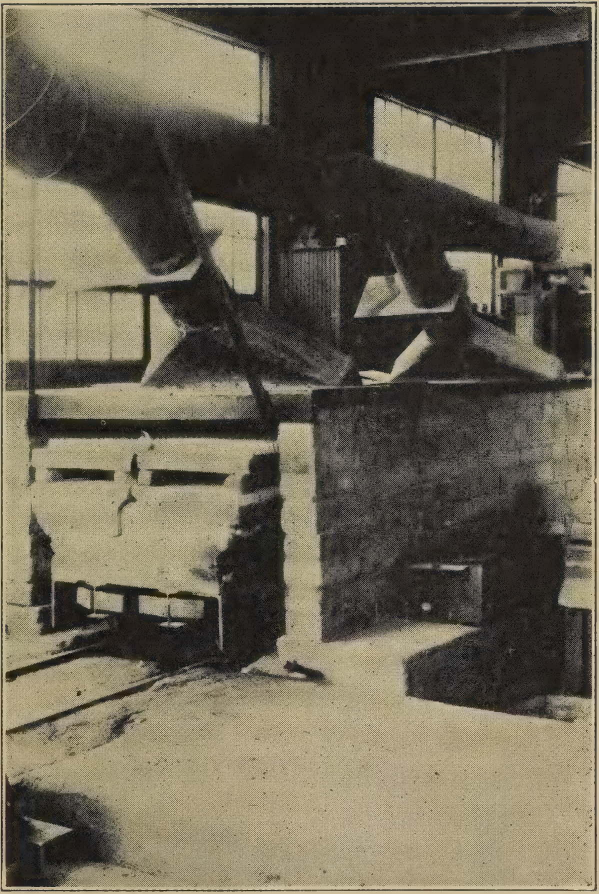

FIG. 2.

Figure 3 shows the temperature curve throughout the length of the kiln. These temperatures were obtained by means of a thermo-couple projecting up through the bottom of a car to the level of the ware. This car was passed through the kiln in the usual manner to a maximum temperature of cone 18 half down. Temperatures were recorded every twelve minutes, or every foot of travel. This curve, therefore, shows the actual continuous heat change to which a piece of ware is subjected.

Cones show practically no variation from side to side of the car top. Cones 17 and 18 are placed on cars where they may be seen from the entrance opening of the kiln in order to serve as a check on firing. The operator watches the cones as closely as he does the pyrometer.

The burner equipment is adjusted to maintain a desirable kiln atmosphere. The combustion gases pass over and around the ware as it advances through the preheating zone and are finally carried off by a stack at the entrance of the kiln. No serious attempt has been made to utilize the waste heat.

The temperature of the gases in the stack is approximately 100°C, the gases being diluted with air from the entrance of the kiln, which accounts for their low exit temperature.

The absence of a complicated construction in the kiln permits a more rapid elevation of the temperature upon lighting than is usually the case with tunnel kilns. Approximately 36 hours elapse from the time of lighting until the ware is started in.

The idea in designing a continuous tunnel kiln of such small dimensions was based upon firing a small mass at a rapid rate. Attempts have been made to fire comparatively large masses of ware at a rapid rate, but with disastrous results.

The benefits of this kiln are limited to the firing of ceramic wares composed of such materials and of such dimensions or so grouped as to

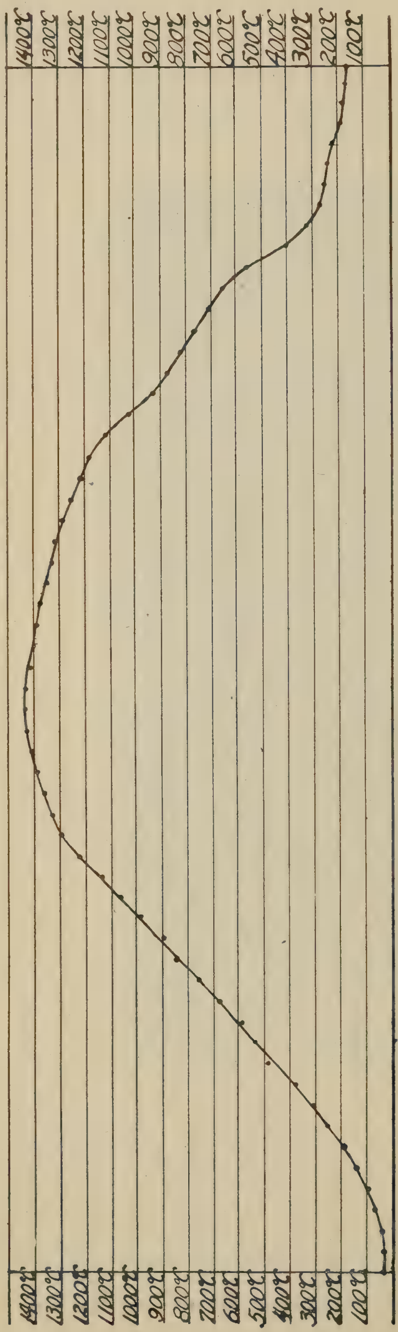

Fig. 3.

be capable of absorbing sufficient heat to produce vitrification in a comparatively short length of time.

It is a very desirable type of kiln in which to fire bodies containing those synthetic fluxes, which are susceptible to objectionable crystalline growths unless properly cooled.

The flexibility of control of the kiln atmosphere enables the maintenance of oxidizing, neutral or reducing conditions as the ware may demand.

This kiln was originally built more or less as an experimental unit, but its operation was so successful that it has been used in production almost continuously since its installation.

With gas at 87 cents per thousand cubic feet, the cost of the burning operation is slightly less than the cost of burning in coal fired periodic kilns. And greater uniformity of product is obtained due to uniform heat treatment.

A new kiln of similar design has been constructed and has just recently been put into operation. This kiln is 87 feet in length and has an interior width of 5 feet 2 inches, or twice the width of the original kiln. Uniform temperatures are also obtained over this greater width. This kiln only requires approximately one-third more fuel to operate than the original kiln and yet has more than twice the capacity.

Protection on both design and process has been allowed by the U. S. Patent Office.

In conclusion, the writers wish to express their appreciation to Mr. Taine G. McDougal for his assistance in the preparation of this paper.

Discussions

By C. B. Harrop:—For the firing of a shallow layer of small size ware, made from a body mix that will stand rapid heating and cooling, the above-described kiln is undoubtedly a real success. However, for capacities such as are being secured from some of the other tunnel kilns firing sanitary ware, general ware and electric porcelain, this type of kiln would undoubtedly be out of the question.

The writer has been much interested in this kiln and in reports that have filtered in concerning it, ever since it was put into operation, although for some reason the construction and operation of the kiln have always been kept close secrets by the owners.

The *surface combustion* firing equipment is probably responsible to a large extent for the success of the kiln. Any other system of fuel application would undoubtedly result in so much greater volumes of combustion gases that the temperature at the charging end of the kiln would be excessive and serious damage would occur to the entering ware. The *surface combustion* principle of firing gives an intense temperature in a restricted space which is absolutely necessary in a kiln of this length.

If the authors had given more real operating data their paper would be of far greater practical value. It would be very interesting to know:

(*a*) Tonnage or number of pieces fired per 24 hours.
(*b*) Cubic feet of gas required per 24 hours.
(*c*) Total power required to operate kiln.
(*d*) Labor required to operate kiln.
(*e*) Cost of repairs—average over a long period.
(*f*) Approximate total cost of kiln.

BY A. W. BUCKINGHAM:—The following discussion consists mainly of questions on points which should be emphasized in view of the fact that this kiln differs in a number of respects from the other makes.

Two features of this kiln illustrate a tendency in present day kiln construction which make for better control: First, the cross-section of this kiln is as small as possible, consistent with the production required.

Second, the large number of burners in the firing zone undoubtedly permits considerable flexibility in "soaking" time.

Other points have occurred in reading this paper which we believe the author should have brought out:

1. What is the approximate cost of the different kilns?

2. It is natural to suppose that heating up and cooling down a tunnel kiln would cause more or less wear and tear on the structure. The author states that after two years of operation there has been very little damage to the kiln on account of this intermittent operation. To what particular features of the construction or operation does he attribute this?

3. The width of the kiln is given in the paper but not the height of the crown of the arch above the deck of the kiln car. It would be interesting to know how much air space there is above the material being fired.

4. Drop arches in the preheating zone should serve as an effective baffle provided they extend down fairly close to the deck of the kiln car. How much below the crown of the main arch do these baffles extend?

5. Manufacturers of this grade of ware would be interested in learning what the unit fuel consumption is, that is, cubic feet of gas per ton of ware, etc.

6. The method of taking temperature for the full length of the kiln at 12 minute periods is a novel one and certainly should be very accurate. Does the author suggest this as being a practical method of taking temperatures at frequent intervals throughout the day?

7. The second installation is described as being about twice the width of the smaller one. What is the total burning time in the longer kiln as compared to the 12 hours for the first installation?

BY A. F. GREAVES-WALKER:—The kiln described is what would be termed a "Sport" in botany. It will do excellent work on such wares as spark plug porcelains which are very small or on wares of thin section, or it could be used for decorating on some classes of ware.

It is an unqualified success; is cheap to construct and easy and cheap to operate. Furthermore, it is the ultimate in quick results.

It is out of the question, of course, to consider the use of this type of kiln for the vast bulk of ceramic products. The further development of its limited use is a question of the future.

COMPARATIVE TESTS OF AMERICAN AND FOREIGN TABLEWARE[1]

By H. H. Sortwell[2]

ABSTRACT

The absorptions, porosities, and bulk specific gravities are given. It was found that the American wares were superior to the English, French, German, and Japanese wares tested in resistance to either crazing or sudden temperature changes. The American hotel wares withstood much greater impact than the imported hotel wares, and the domestic earthenware and china for household use was superior to the foreign chinas tested, which were brittle. The resistance of hotel wares to chipping at the edge appeared to depend more on the design of the edge and the angle of inclination of the rim, than on the inherent properties of the bodies. All of the glazes were found to be unaffected by boiling in alkaline solutions for a period of twenty-five hours.

Introduction

In connection with the devising of specifications to be used by the various government purchasing agencies in the selection of tableware, the Bureau of Standards has made a number of tests on a large variety of wares.

The devising of specifications of quality involves two problems: first, the study of various tests to develop simple, practical methods which will give a criterion of the service to be expected from the wares tested; and second, the study of a large number of wares by these tests to determine limits of quality which will serve as an aid to the purchasing agent in making his selections, and at the same time be fair to the potter and protect him from unreasonable demands.

This paper consists of an exposition of the tests studied, and a presentation of the data obtained by conducting them on a large variety of wares. For the purpose of comparison, representative French, German, English, and Japanese products which in ordinary times have been imported in large quantities, were included. Some of the wares were acquired by purchase, some were contributed by potters, and a number were obtained from a supply depot of the United States Public Health Service. The data resulting from the preliminary work to the present time refer to absorption, porosity, and bulk specific gravity, resistance to crazing and sudden temperature change, resistance to impact, resistance to chipping, and resistance to alkaline solutions.

Due to the limited number of samples tested these results can not be taken as an accurate criterion of the continuous output of the various potteries, but they are such results as would be obtained in testing lots of ware for purchase by specification, and they show the distinct differences in the different types of ware tested.

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[1] Published by permission of the Director, Bureau of Standards.

[2] Received April 1, 1922.

Absorption, Porosity and Bulk Specific Gravity

In determining absorption, porosity, and bulk specific gravity boiling the pieces in water one hour followed by a soaking period was considered a sufficiently accurate means of saturation for the practical, comparative test desired. About forty grams of pieces approximately one inch square broken from the centers of plates were used in each determination. After drying at 110°C the pieces were weighed, boiled in water one hour, and allowed to remain in the water eighteen hours after the boiling. By this procedure the pieces were boiled on one day from three to four P.M. and the following morning at ten A.M. were weighed suspended in water, after which they were wiped off with a damp cloth and weighed again.

The computations were made by means of the following formulas:

$$\text{Per cent absorption by weight} = 100 \times \frac{W - D}{D}$$

$$\text{Per cent apparent porosity by volume} = 100 \times \frac{W - D}{W - S}$$

$$\text{Bulk specific gravity} = \frac{D}{W - S}$$

in which D is the dry weight, S the weight of the saturated pieces suspended in water, and W the weight of the pieces saturated with water.

The results given in Table I are averages for six plates of each make, and show that the American hotel chinas are not in some cases fired to zero absorption. One ware, No. 10, had an absorption of 1.4 per cent. Two of the American hotel wares were earthenware as shown by absorptions of 7.9 and 9.8 per cent, and one, No. 11, was about half way between the earthenware and vitreous china in absorption.

The English hotel wares were not vitrified, the absorptions ranging from 2.7 per cent to 6.0 per cent, while the French and German hotel wares were completely vitrified to a glassy structure.

The American earthenware, commonly called semi-porcelain or semi-vitreous china, varied in absorption from 7.4 per cent to 10.2 per cent. The one domestic vitrified ware for household use included in the work was practically the same as the hotel ware made by the same pottery. All of the imported china for household use was completely vitrified and of glassy fracture.

In general a distinct difference was noted between the American vitreous wares on the one hand and the French, German, and Japanese wares on the other. The domestic bodies had a comparatively granular structure indicating that fusion and solution had not progressed as far toward forming a homogeneous glass as in the imported wares which were all of a glassy

Table I

Results of Absorption, Porosity, Bulk Specific Gravity, Impact, and Chipping Determinations

No.	Type of ware	Ave. % abs.	Ave. % por.	Ave. bulk sp. gr.	Ave. impact energy ft. lbs.	Ave. thickness at break in inches	Ave. impact energy to chip ft. lbs.
1	Hotel ware, rolled edge	0.0	0.0	2.36	0.200	0.213	0.400
2	Hotel ware, rolled edge	.0	.0	2.30	.250	.215	.250
3	Hotel ware, rolled edge	.0	.0	2.30	.300	.212	.250
4	Hotel ware, rolled edge	.2	.4	2.40	.300	.194	.275
5	Light hotel ware, plain edge	.0	.0	2.40	.175	.190	.125
6	Hotel ware, rolled edge	.6	1.4	2.38	.275	.234	.350
7	Hotel ware, rolled edge	.8	1.9	2.38	.275	.187	.275
8	Hotel ware, rolled edge	.3	.7	2.38	.200	.222	.275
8*a*	Heavy hotel ware, plain edge	.3	.7	2.38	.250	.259	.325
9	Hotel ware, rolled edge	.0	.0	2.30	.150	.172	.125
10	Hotel ware, rolled edge	1.4	3.2	2.33	.400	.203	.225
11	Hotel ware, rolled edge	4.8	10.5	2.16	.225	.246	.125
12	Hotel ware, rolled edge	7.9	16.2	2.05	.250	.156	.100
13	Heavy hotel ware, plain edge	9.8	19.9	2.03	.225	.238	.200
14	English hotel ware, rolled edge	3.4	7.7	2.33	.150	.215	.300
15	English hotel ware, rolled edge	6.0	13.5	2.23	.150	.193	.225
16	English hotel ware, rolled edge	2.7	6.1	2.23	.125	.190	.200
17	English hotel ware, rolled edge	5.1	10.8	2.13	.175	.157	.150
18	French hotel ware, plain edge	.0	.0	2.18	.100	.194	.100
19	German hotel ware, rolled edge	.0	.0	2.33	.125	.168	.375
20	German hotel ware, rolled edge	.0	.0	2.35	.100	.214	.125
21	Household ware, semi-vitreous	8.5	17.1	2.01	.175	.155	..
22	Household ware, semi-vitreous	10.2	20.3	1.98	.175	.184	..
23	Household ware, semi-vitreous	7.4	15.2	2.05	.175	.162	..
24	Household ware, semi-vitreous	8.4	17.1	2.04	.200	.145	..
25	Household ware, semi-vitreous	7.9	16.2	2.06	.200	.162	..
26	Household ware, semi-vitreous	9.6	19.2	1.99	.200	.182	..
27	Household ware, semi-vitreous	8.7	17.5	2.03	.175	.154	..
28	Household ware, semi-vitreous	8.2	17.2	2.10	.175	.159	..
29	Household ware, vitreous	.0	.0	2.32	.225	.160	..
30	Japanese household ware	.0	.0	2.23	.100	.180	..
31	Japanese household ware	.0	.0	2.29	.100	.188	..
32	French household ware	.0	.0	2.20	.075	.122	..
33	French household ware	.0	.0	2.25	.150	.134	..
34	German household ware	.0	.0	2.38	.150	.150	..
35	German household ware	.0	.0	2.35	.150	.110	..

nature and of corresponding translucency. This difference in body structure has an important bearing on the properties of the wares as shown by other tests.

The vitrified wares varied in bulk specific gravity from 2.20 to 2.40, the American earthenware was uniformly about 2.00, and those wares lying between the two in absorption and porosity had intermediate specific gravities.

Crazing Test

In the selection of a test for crazing several methods which have been formerly used were tried. Repeated transfer of ware from boiling water to ice water has sometimes been used for such a test.[1] Since the strains which the pieces undergo in this treatment are equaled in a short time by the ware passing through the modern dishwashing machines this test is not severe enough to approximate conditions of long usage. Many vitreous and semi-vitreous plates were passed from boiling water to ice water and vice versa twenty-five times without the occurrence of any crazing whatever. To be valuable in differentiating between wares in regard to crazing tendency this treatment would have to be repeated such a large number of times as to make its use tedious and impractical.

The test used by Ashley[2] consisted of chipping the edges of plates and boiling them eight hours in a saturated solution of sodium chloride, after which they were dried. The crazing which results from such treatment is caused by the crystallization of the salt beneath the surface of the glaze in the porous body. Since the amount of salt crystallizing determines the strain under the glaze it is evident that while this test gives a comparison of glaze fit on two bodies of the same porosity it would not give a fair comparison when the porosities differ. This test is of value to the potter who is testing plates of approximately the same porosity from time to time, but could not reasonably be used to compare for instance a semi-porcelain of eight per cent absorption and a vitrified ware.

A crazing test for tableware based on quenching the ware at temperatures of from 120°C to 200°C in water at room temperature was studied by Harkort.[3] The cause of crazing in such a test is primarily the difference in coëfficient of expansion of body and glaze, and corresponds closely to the causes of crazing of ware in actual use. He found that ware which would withstand quenching from 190°C to room temperature was safe from crazing for two and a half years, the extent of his observations. In developing a test for crazing of wall tiles Pence[4] also suggests such a test, he having found that quenching from 163 °C to 0 °C was a reasonable guarantee against crazing in that type of ware.

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[1] Stover, *Trans. Amer. Ceram. Soc.*, **11,** 89 (1909).

[2] Ashley, *Ibid.*, **9,** 59 (1907).

[3] Harkort, *Ibid.*, **15,** 368 (1913).

[4] Pence, *Ibid.*, **18,** 622 (1916).

After preliminary experimenting at different temperatures it was decided that several immersions in the neighborhood of 180 °C would give a reliable indication of freedom from crazing in use including a margin of safety. Since it was found that the technical staff[1] of one of the larger potteries had reached a similar conclusion, the test adopted consisted in quenching five inch plates at 175 °C in tap water (15–20 °C) ten times. Ware which will stand this treatment without crazing may be safely relied on to stand up in service. Repeated immersion is to be desired in preference to a single immersion at a higher temperature since it minimizes variations which might enter from unequal heating.

Before quenching the plates were heated in an electric furnace from twenty minutes to half an hour to insure uniform temperature conditions as indicated by a thermometer at different places on the specimens. After ten immersions at 175°, the plates were quenched five times at 200°, five times at 225°, and five times at 250°. Quenching at these higher temperatures is a very severe test, far more rigorous than ordinary service, and was conducted simply to give a measure of the margin of safety present in the various wares.

The results given in Table II are averages on several five inch plates of each make, the number depending on the agreement of the results obtained. Variations were noted in different pieces of some brands but in most cases like pieces checked within one or two immersions. Owing to the fact that five inch plates of some brands were not available not all of the wares listed in Table I could be included in this test.

It was found that most of the vitreous bodies would not stand the sudden change at the higher temperatures as cracking of the plates would result. Ability to withstand moderate temperature changes is important because those wares which will not rupture in the greater thermal shock are less apt to weaken from the repeated scalding to which they are subjected in the dishwashing machines. Therefore, in addition to being a test for crazing, this treatment gives a measure of the ability of the wares to withstand sudden temperature changes.

Of the six brands of domestic hotel ware tested none crazed from quenching at 175°. One ware crazed on the third immersion at 200°, and one on the second at 225°. One brand cracked at 225°, and three at 250°. Two wares, No. 1, vitreous, and No. 11, semi-vitreous, stood the entire treatment without crazing or cracking.

The four brands of English hotel ware crazed easily, one on the second quenching at 175°, two on the third, and one on the seventh, and consequently would not pass specifications based on this test.

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[1] Communication from A. V. Bleininger.

TABLE II

RESULTS OF CRAZING TEST

No.	Type	Immersion on which failure occurred																								
		175°										200°					225°					250°					
		1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
1	Hotel china	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	O.K.
2	Hotel china	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	× Cracked				..	
5	Hotel china	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	× Cracked								
7	Hotel china	..	..	..	..	..	..	..	..	..	..	..	..	× Crazed			..	..	..	..	..	..	..	× Cracked			
8	Hotel china	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	× Crazed				× Cracked					
11	Hotel china, semi-vitreous	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	O.K.
14	English hotel ware	..	..	..	..	..	..	× Crazed																			
15	English hotel ware	..	..	× Crazed																							
16	English hotel ware	..	× Crazed																								
17	English hotel ware	..	..	× Crazed																							
18	French hotel china	..	..	..	..	× Cracked																					
19	German hotel china	..	..	..	..	..	..	..	..	..	..	..	..	× Cracked													
20	German hotel china	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	× Cracked								
21	Semi-vitreous china	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	× Crazed									
22	Semi-vitreous china	..	..	..	..	..	..	..	..	..	..	..	× Crazed														
23	Semi-vitreous china	..	..	× Crazed																							
24	Semi-vitreous china	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	× Crazed										
25	Semi-vitreous china	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	O.K.
26	Semi-vitreous china	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	× Crazed					
27	Semi-vitreous china	,.	..	..	..	..	..	..	..	..	..	× Crazed															
28	Semi-vitreous china	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	O.K.
30	Japanese china	..	..	..	..	..	..	..	..	..	..	..	..	..	× Cracked												
31	Japanese china	..	..	..	..	..	..	× Cracked																			
32	French china	× Completely shattered																									
33	French china	..	..	..	..	..	..	..	..	..	× Cracked																
34	German china	.,	..	..	..	× Cracked																					
35	German china	..	..	..	..	..	..	..	..	..	..	..	..	..	× Cracked												

Although no crazing developed in the French and German hotel wares included in the work they showed a greater tendency to rupture from sudden temperature change, the French ware failing on the fifth immersion at 175°, one German product on the third at 200° and the other on the third at 225°.

Of the eight semi-vitreous household wares tested only one failed to stand the treatment at 175°. No. 23 crazed consistently on the third immersion. Two brands crazed on the second and third quenchings at 200°, two at 225°, and one at 250°. Two semi-porcelains withstood the entire treatment without failure. One of these, No. 28, was made wholly from domestic materials and gives an encouraging indication of the possibility of their greater use.

Two interesting deviations from ordinary crazing were noted in some specimens of this type of ware. Some plates would appear to be crazed but close examination would show that the fracture was at the point where body and glaze meet and did not reach the surface to produce an open crack. After a short time these marks would disappear leaving no sign whatever that the crazing beneath the surface had occurred. When this phenomenon appeared it was usually noticed on the first and second immersions before normal crazing occurred.

The other unusual crazing was noted only at the highest temperatures used. When some specimens were taken from the furnace at 250° craze marks were plainly visible but on quenching the piece they would entirely disappear and could not be located by washing the plate with red ink. These observations would indicate that in this case the coefficient of expansion of the body in the temperature range below 250°C was greater than that of the glaze, and on heating to 250° the difference in expansion was sufficient to cause crazing. When the ware was chilled to room temperature the glaze came together again so that no crazing of practical importance was present.

No crazing appeared in the foreign chinas for household use but all were susceptible to sudden temperature changes. One of the Japanese wares cracked on the seventh quenching at 175° and the other on the fourth at 200°. The specimens of one of the best known brands of French china were completely shattered on the first immersion at 175°, while the other French ware cracked on the tenth immersion at the same temperature. One of the German products cracked on the fifth treatment at 175° and the other at the fourth at 200°.

The effect of the structure of these bodies on their ability to withstand sudden temperature changes is clearly evident, the porous wares withstanding quenching at 250° without failure, the vitrified but still granular American bodies not failing until 225° or 250° and the glassy French, German, and Japanese wares failing on treatment at 175° and 200°, one German ware, however, not failing until 225°.

A summary of the results of the crazing test shows that the domestic hotel wares included in the work were safe from crazing in service, and only failed from sudden temperature change at the highest temperatures employed. The English hotel wares crazed comparatively easily, while the French and German wares tested did not craze but cracked on quenching at 175°, 200° and 225°. With one exception the domestic semi-porcelains studied did not craze during ten quenchings at 175° but crazed at the higher temperatures, two, however, withstanding the entire treatment. The French, German, and Japanese household chinas ruptured on immersion at 175° and 200°.

Impact Tests

For the impact test a modification of the pendulum apparatus devised by Staley and Hromatko,[1] shown in Fig. 1, was used. The steel disc "a" weighed six ounces and was nine-sixteenths inches thick and one and three-quarters inches in maximum diameter. The edge was rounded at a radius of five-eighths inch. Into it was soldered the stiff wire arm "b" of such length that the distance between the center of the disc and the point of suspension was two feet. At the upper end of the arm was the scale "c" which consisted of a ninety degree segment of a sixteen inch circle calibrated in divisions of 0.025 foot pound energy of impact. The formulas used in calculating the relation of angular fall to energy of impact have been given by Staley and Hromatko.[2]

The pendulum and scale were supported by a heavy adjustable stand. The plates were seated against three one-eighth inch ball bearings equilaterally placed in a circle three and one-quarter inches in diameter in the ring "d" which was firmly fastened to a solid backing.

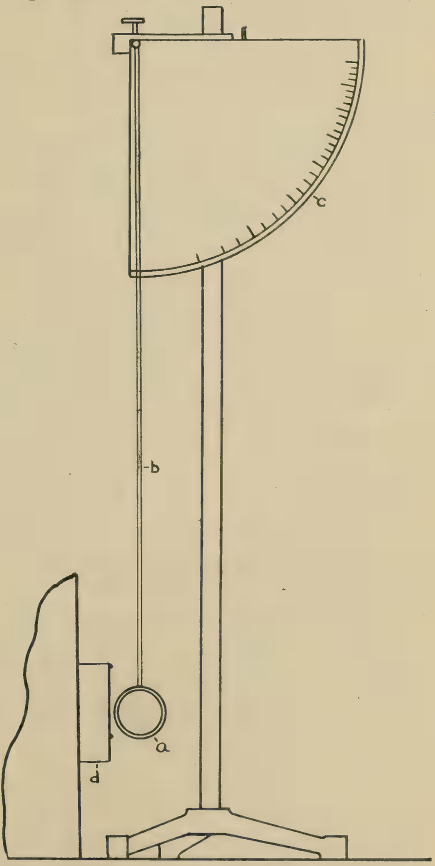

Fig. 1.—Apparatus used in impact tests.

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[1] Staley and Hromatko, *Jour. Am. Ceram. Soc.*, **2**, 227 (1919).

[2] *Loc. cit.*

It was found that striking the plates in the center seated against the three balls gave more consistent results than striking them at one point on the foot with the outer edge seated against the bearing board, or by applying the blow at the center with the plates seated against a steel ring. The three points established a solid seating regardless of the warpage of the plates and afforded a firm base with none of the variations which might enter from cushioning the plate to overcome the effects of warping.

The fracture produced when plates are broken in this way usually occurs in lines radiating from the center of the plate. Complete fracture or cracks which weakened the piece sufficiently to be pulled apart by the hands were considered failure. Occasionally a hole was broken through the center, but this was usually due to defects in the structure of the plate.

While this fracture does not exactly duplicate that occurring when a plate breaks in falling, it was thought that the uniformity and consistency of the results obtained warranted its use for a comparative test.

In testing, a plate was held with the bottom resting lightly but solidly against the seat and was struck in the center. Ordinarily the first blow was 0.100 foot pound and each successive blow increased in intensity by 0.025 foot pound until failure occurred. In testing the wares that had a very low resistance to impact the first blow was 0.025 foot pound. These very light blows had no noticeable effect on the stronger wares.

The average results from the breaking of at least six plates of each kind are shown in Table I. Owing to lack of knowledge of the factors involved in the impact test it is impossible to derive mathematically the relation between the thickness of the plates and their ability to withstand impact. On this account the impact energy computed into units per unit thickness can not fairly be used for comparison of wares of different thickness and is consequently not given in the results. It is believed that this relation will be established empirically in the near future by the correlation of data from tests of ware made for the purpose, in which thickness is the only variable. The thickness of the plates is given solely for comparison.

With two exceptions the thirteen brands of American hotel ware required an average blow of from 0.200 to 0.400 foot pound to cause fracture. One ware, No. 5, a light weight hotel ware, broke at 0.175 foot pound and No. 9 fractured at 0.150 foot pound. The strongest ware tested was No. 10 which had an absorption of 1.4 per cent and required a blow of 0.400 foot pound to cause failure. The three semi-vitreous wares, Nos. 11, 12, and 13 compared favorably with the vitrified products.

The four English brands were not as strong as the American wares and failed at 0.125, 0.150, 0.150, and 0.175 foot pound, while the French and German wares tested were brittle and fractured at 0.100, and 0.125 foot pound, respectively.

The results obtained on the hotel wares are shown graphically in Fig. 2, giving both the blow to cause fracture and the thickness of the ware, which shows clearly that in regard to ability to withstand blows as indicated by these tests the American wares are much superior to the French, English, and German wares tested.

The eight brands of semi-vitreous ware for household use required an average impact energy of from 0.175 to 0.200 foot pound to cause failure while the one vitreous American ware broke at 0.225 foot pound. No. 28, the semi-porcelain made entirely from domestic materials, compared favorably with the others of that type.

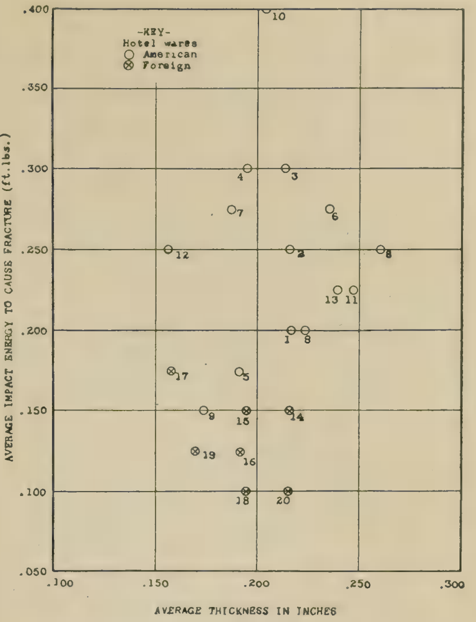

FIG. 2.—Results of impact tests on hotel wares.

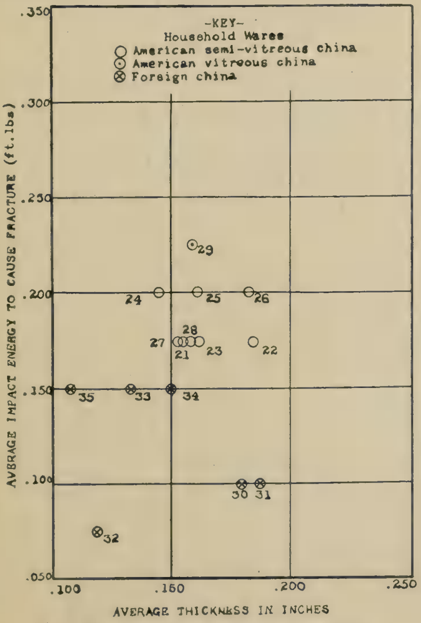

FIG. 3.—Results of impact tests on household wares.

The French, German, and Japanese household wares were brittle. One thin French ware failed at 0.075 foot pound and the heavier French ware at 0.150 foot pound. Both German brands failed at an average blow of 0.150 foot pound, and the two Japanese products at 0.100.

Fig. 3 shows graphically the results on household wares and indicates that the domestic wares will stand greater sudden blows than the imported chinas tested.

A comparison of glazed and unglazed pieces of several wares was obtained. No difference could be discerned. Possibly a more delicate test might show the effect of the glaze on the resistance to impact. The effect of the structure of the body on the properties of the ware is again shown. The comparatively granular domestic vitrified wares had a relatively high resistance to impact whereas the impervious, glassy, imported wares were correspondingly brittle with a lower ability to withstand blows.

Chipping Test

The test for clipping used in this work was essentially an impact test applied at the edge of the plate. The same device was used as in the impact test with the exception that the tup was a rectangular block of hardened steel one and one-half by one and one-quarter by one-half inches with the striking edge rounded at a radius of one-quarter inch. Its weight was six ounces so that the same length arm and the same scale for impact energy could be used. The plates were seated horizontally on a heavy stationary iron slab on which were bolted two steel bars forming an angle of ninety degrees, and were struck at the point on the edge so that the blow was absorbed equally at the two points of contact of the edge with the bars. Since its use by the Bureau this general method has been adopted in at least one of the potteries as shown by the paper by Schramm.[1]

In testing, the same procedure was followed as in the impact test, the plate being struck with a blow of 0.100 foot pound, each successive blow being greater by 0.025 foot pound, until a chip appeared. The plates were chipped at four different points after it was found that previous chips had no apparent effect on the results at other points. Only the hotel wares were given this test.

The results obtained were not as consistent as might be desired as different points on the same plate in some cases varied as much as different plates of the same set, but the average results obtained showed considerable variations between different brands. The results given in the last column of Table I are averages for a minimum of twelve chips on at least three different plates of each make.

Comparison of these results with those obtained from the impact test shows that there was no direct relation between them. This may be attributed in large part to the influence of the design of the edge and the angle of inclination of the rim. In fact, it is shown by the data that plates of equal or similar body properties, but of different edge design differed so widely as to justify the conclusion that the latter factor had as great an effect on chipping as the inherent properties of the body.

The average energy to cause chipping varied from 0.100 to 0.400 foot pound. In some cases the energy required to produce a chip was greater than that required to fracture the plate when struck in the center. The majority of the wares required a good hard blow to produce a chip.

[1] Schramm, *Jour. Am. Ceram. Soc.*, **5**, 136 (1922).

Some wares, Nos. 5, 9, 11, 12, 17, 18 and 20, were more prone to chipping as indicated by lower results, and the cause could usually be ascertained by examination of the chipped plates. The low value for No. 5 was due to the thinness of the edge and the low angle of inclination of the rim which was almost horizontal. No. 9 was brittle as shown by its giving the lowest results in the impact test, of the American wares tested. The early failure of No. 11 was in part due to the fact that the striking edge of the plate received the blow in such a way that a chip was sheared off instead of transmitting the blow uniformly to the body of the piece. No. 12 failed for the same reason, and the result on No. 17 can be partly attributed to this factor. The French ware, No. 18, was the most brittle hotel ware tested and consequently gave a low value for chipping. Its design was also conducive to this. No. 20 also failed at a blow comparative to its low resistance to impact.

Owing to the fact that plates with similarly designed edges were not available no conclusive evidence as to the comparison in resistance to chipping of the American vitreous and semi-vitreous hotel wares was obtained.

The domestic wares gave good results with the exceptions of those affected by poor design. One of the English wares gave a high value, two were fair, and one poor. The French china chipped very easily, and one German ware gave next to the highest result obtained while the other resembled the French ware.

The results show the great importance of the design of the rolled edge on the ability of the ware to withstand blows at the edge. An investigation of interest and importance to the potters making hotel ware would be the testing of a large number of plates of all the different designs in use made by one workman from one body and fired in the same kiln, to determine the designs giving the greatest resistance.

Resistance to Alkaline Solutions

In use the glaze on tableware is subjected to hot, dilute, alkaline dishwashing solutions, while the acids with which it comes in contact are weak, usually dilute, and are at moderate temperatures. In order to determine the effect of such solutions as are used in dishwashing machines, plates of each make were boiled six hours in a half normal ($3^1/_2$ oz. per gallon) solution of sodium carbonate, and six hours in an approximately 4 N (27 oz. per gallon) solution. No effect of this treatment could be noticed.

It was thought that the effect of the dishwashing solutions might take place after the surface of the glaze had become marred by cutlery marking and abrasion. Plates of several representative makes of each type of ware were accordingly scratched with a diamond point so that the solution could come in contact with the glaze beneath the glossy surface. Two plates of each kind were scratched, one for treatment and one to be kept for comparison.

The plates were then boiled in a half normal solution of sodium carbonate, and examined at intervals to note any effects of the treatment. At the end of twenty-five hours' boiling the plates were removed, thoroughly rinsed in hot water, and examined. No effects of the solution were visible on any of the plates. Microscopic examination at a magnification of 250 failed to show any difference between the plates treated and those kept for comparison.

These results indicate that the glazes now in use on tableware are capable of withstanding alkaline dishwashing solutions over a long period of time.

An important test to be developed is one that will give a measure of the resistance of the glaze to cutlery marking and abrasion. While some experiments have been made in this direction no entirely satisfactory results have been reached at this time.

The author wishes to thank those potters who have shown their interest in the work by contributing ware for the investigation.

Bureau of Standards
Washington, D. C.

NOTES ON DIAGNOSING CAUSES OF CORDS IN GLASS

By F. Twyman[1]

ABSTRACT

The physical properties, *e. g.*, refractivity, viscosity, and expansion coefficient, of cords generally differ from those of the mass of the glass. Methods are described for rapidly ascertaining the relative values of these properties. This information, together with a knowledge of the batch ingredients and possible impurities may afford in certain cases a means of determining the cause of the cords.

A great deal of information may often be obtained very rapidly by using the following methods of examination:—

1.—Are the cords of higher or lower refractive index than the mass of the glass?

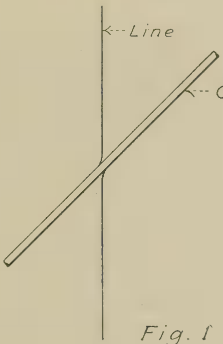

Fig. 1

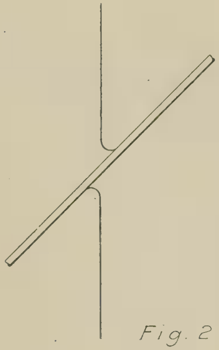

Fig. 2

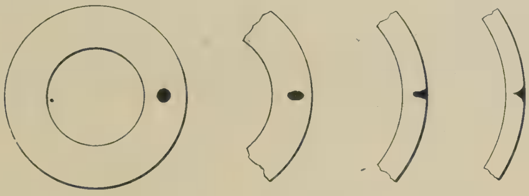

Fig. 3

A straight line, such as a window blind cord or line drawn on paper, is observed through the glass under examination in such a way that the line is intersected obliquely by the cord. The line should not be too far away, nor the glass too near the eye, in order that both should appear simultaneously in focus. A cord of high refractive index would then cause distortion as in Figure 1, and one of low refractive index as in Figure 2. It is obvious that precisely the same effect would be caused by a streak irregularity in the surface—a ridge in the first case and a depression in the second; and some such irregularity is nearly always present in the cords which occur in practice.

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[1] Published by kind permission of Messrs. British Glass Industries Ltd., to whom the author's thanks are due.

In all but the most extreme cases, however, the refractive index effect would outweigh that due to irregularity of surface. Immersion in a homogeneous liquid of suitable refractive index would in any case eliminate this source of error.

2.—Is the cord of higher or lower viscosity than the remainder of the mass?

If a cross-section is taken along the cord, and its direction noted, particularly whether it emerges from the glass surface (as it frequently does), one can generally state whether the cord was of higher or lower viscosity than the remainder of the glass when moulding occurred.

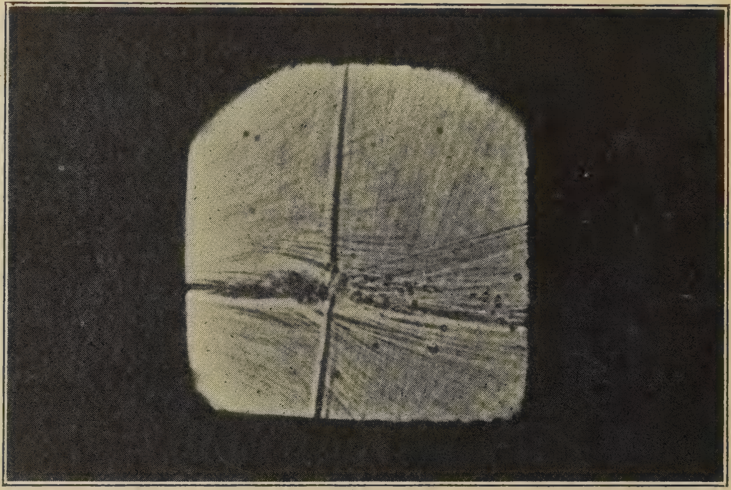
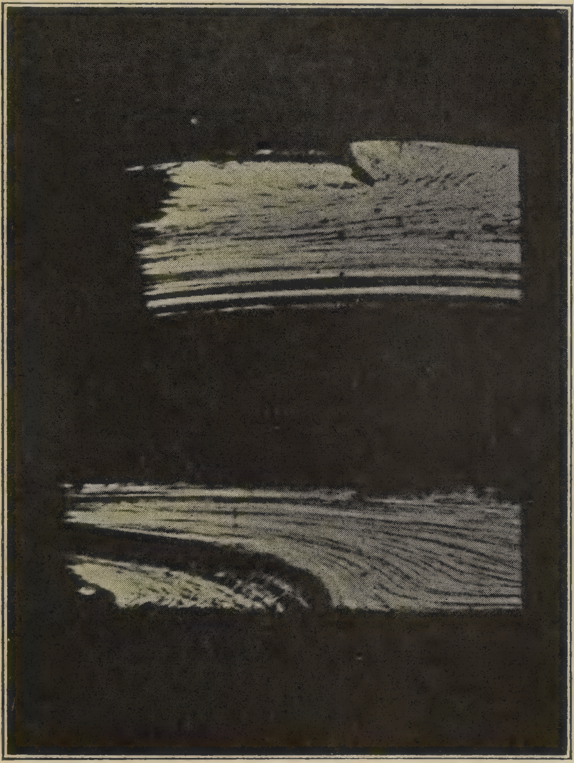


Fig. 4.

In the diagram (Fig. 3) the left hand figure represents the cross-section of a gathering in process of blowing, and the black dot is a cord. Then the cord will flow outward in a more or less stream-like manner, finding an outlet at the free surface, as indicated by the successive figure to the right, and if of lower viscosity it will at the surface flow over the remainder of the glass. If it is of higher viscosity this will not occur, but the remainder of the glass will flow over it.

This effect may be further illustrated by the photographs reproduced. Figure 4 is a low power photomicrograph of a portion of the side of a bottle, viewed through the side in the ordinary way, but with the surfaces ground and polished. Two cords are seen crossing at right angles, one clear and distinct, the other rather diffuse. The former was due to a fold in the glass, the latter to a cord such as I have described. Cross-sections of each of these cords were cut by planes perpendicular to the plane of the paper. These were polished and photographed. That of the vertical cord (Fig. 5) which the original sample showed clearly as a fold, is not quite so convincing in the photograph. The other cord, however, shows in cross-section (Fig. 6) a decided streaming outwards, and it should be noted that a streak of severe double refraction was present in the glass which coincides with the stream, and which could not be removed by annealing.



Figs. 5 and 6.

3.—Had the glass in the neighborhood of the annealing temperature a higher or lower coefficient of expansion?

If by observation in polarised light the direction of strain is noted within the cord, namely, whether it is compression or extension, one can immediately say whether the coefficient of expansion of the substance of the cord was higher or lower than that of the mass of the glass.

4.—Occasionally devitrification occurs within the cord. If this is the case, it indicates a high probability that the cord is more liable to devitrification than the remainder.

Generally speaking, cords are not the result of devitrification of a portion of the glass of the same composition as the mass. On the contrary, in those cases when devitrification is present within the cords, the glass forming the cord has been contaminated in such a way, for example, by excessive lime content, as to give rise to devitrification.

All cords examined by the writer have had physical properties differentiating them in a marked degree from the mass of the glass. It does not appear that cords can occur in a homogeneous melt, even though, in the process of gathering and moulding, extreme differences of temperature and consequently of viscosity, have been temporarily introduced. There is, indeed, an action which tends to rapidly efface such differences of temperature. Those regions which are hotter are, of course, less viscous, and in the blowing rapidly become thinner than the remainder. Once thinner, radiation soon renders them cooler than the remainder; and it is then the latter which begins to get thin more rapidly. Briefly, then, so long as one portion of the article is thicker than the rest, it remains hotter, and hence gets thin more rapidly; while so long as one portion is thinner than the remainder it soon gets cooler, and therefore gets thin more slowly. There is thus a powerful influence at work, tending towards uniformity alike of thickness and temperature. Folds of course do occur owing, probably, to a very sudden chilling of that portion of the glass which touches the mould first.

Contamination may easily occur through the careless introduction into the furnace of some substance of low surface tension, followed immediately by such a substance as will float, and, by dissolving, cause cords—lime, for instance—which will be carried rapidly across the surface in an undissolved state, unless an effective surface baffle is employed, thus increasing locally the lime content. Or the impurity (*e. g.*, lime) may by its own solution, cause variations of surface tension, causing it to travel across the surface.

If, then, the co-relation between

(*a*) refractive index,
(*b*) viscosity,
(*c*) coefficient of expansion,
(*d*) liability to devitrification,

and the various constituents or impurities of the glass are known, a very rapid diagnosis may be made in many cases, and may immediately fix the cause of the cords.

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Discussion

By G. W. Morey:—Careful study of the imperfections in glass may be made to yield information of great value to the glassmaker, and often may suggest a modification of procedure which will eliminate the cause of the imperfection. The determination of the relative refractive index by the method suggested, which is essentially that already described by Wright,[1] is of especial value in ascertaining the source and cause of cords and striae and has many times proven serviceable to me. It is surprising how prominent a cord appears whose difference in refractive index from the surrounding glass is only one point in the third decimal place, and this amount is generally sufficient to enable one to ascertain which of the two has the higher refractive index, especially if the glass be immersed in a liquid of approximately the same refractive index. In the writer's experience, cords of higher refractive index than the glass are of rare occurrence, and have been caused by insufficient mixing of the melt.

It is correct to state that if the cord has a different coefficient of expansion than the glass, strain will result, but this is caused by the difference of expansion coefficient not only in the neighborhood of the annealing range but also, and more particularly, below the annealing range. Indeed, such glass might be cooled throughout its annealing range in such a manner that no strain appeared, but when cold, strain would be present.

It is of course conceivable that devitrification might take place within the cord, but, as a rule, when crystalline material is found in cords, it is more probable that the crystalline material itself is the cause of the cord. The optical identification of the crystalline material as described by Bowen[2] is of the greatest value in locating the source of cords caused in this manner.

[1] Wright, *Jour. Am. Ceram. Soc.*, **4**, 655–661 (1921).

[2] *Ibid.*, **1**, 594–605 (1918).

DERRY FELDSPAR QUARRY[1]

By N. B. Davis

ABSTRACT

An outstanding development in feldspar at Buckingham, Quebec, where a large deposit of high-grade potash feldspar known as Derry Quarry has been opened up and placed on a shipping basis.

Introduction

For a considerable number of years the country north of Buckingham, Quebec, along the Lièvre River, has produced small tonnages of the highest grade feldspar known, and supplied to the dental trade. This feldspar was usually secured when mining for white mica, and from deposits of very limited size.

Early in 1920 an attempt was made to work one of these small deposits for material suitable for porcelain manufacture but it was found impossible to make ends meet. This lead to prospecting new ground with the idea of discovering a large body, and in September work was started on the outcrop of what may now be described as the largest body of clean straight feldspar known on the continent.

In the various spar districts there appears to be but one deposit of outstanding merit surrounded by a number of small bodies subject to greater variation. This also seems to be the condition in the Buckingham district.

Location

The Derry Quarry is located in the hills above the Lièvre River valley near Glen Almond some nine miles north of the town of Buckingham, and about thirty miles from Ottawa. It is accessible by a good motor road, or by steamer within two miles in summer, and by sleigh in winter.

Geology

The deposit is part of a large intrusive mass of pegmatite that can be traced across country for a mile or more with the greatest development of crystallization on the south half of lot 8, range 1, of the township of Derry. On the south end of this lot the pegmatite has a width of one hundred and fifty feet, and differentiation of spar has taken place on a huge scale. The outcrop shows a width of 50 feet and a length of 300 feet of clean spar crystals, individuals attaining dimensions of 30 feet in length and up to 15 feet diameter.

A cross section of the deposit is somewhat as shown in Figure 1.

Quartz is present in very subordinate amount, approximately 1.5% by actual tonnages separated, a most remarkable record when compared with the general run of such dikes.

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[1] Received March 25, 1922.

Accessory minerals, such as tourmaline and mica, are present only in small amounts near the walls and can be easily separated in the mining operation.

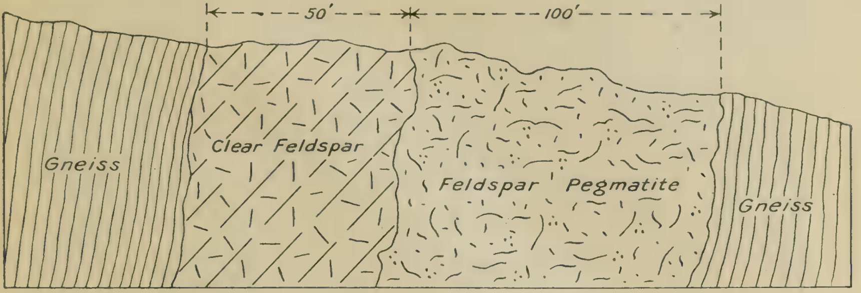

Figure I. Cross section of Derry Feldspar Quarry, Buckingham, Quebec

The feldspar is cream to buff colored and typical analyses of the grade of material shipped are as follows:

	A	B
Silica	65.09	65.80
Alumina	18.85	19.74
Iron	0.029	0.031
Lime	0.21	0.11
Potash	13.42	12.32
Soda	2.11	1.74

(Analyses by Booth, Garrett & Blair, Philadelphia)

Quarry Operation

The present opening is in the form of a side hill cut and with a working face 50 feet high no hoisting will be necessary for a year or more.

Great pains are taken to maintain the original purity of the material. The surface six feet are quarried separate to ensure minimum contamination from seepages. The central 30–40 feet are blasted and mucked out before the wall zones are touched.

Holes are drilled across the face to depths of 8–14 feet and two to three benches carried forward. Each hole is sprung to take the necessary charge of dynamite.

In the pit each man uses a stone fork (no shovels) and as the spar is loaded on flat cars two inspectors watch it for the elimination of any objectionable material that may get past the muckers. The cars are dumped into a 100 ton storage bin to pass by gravity to the wagons or sleighs as required.

In the summer wagons take the material to the river bank where it is dumped into another loading bin and to a 40 ton scow to be transported

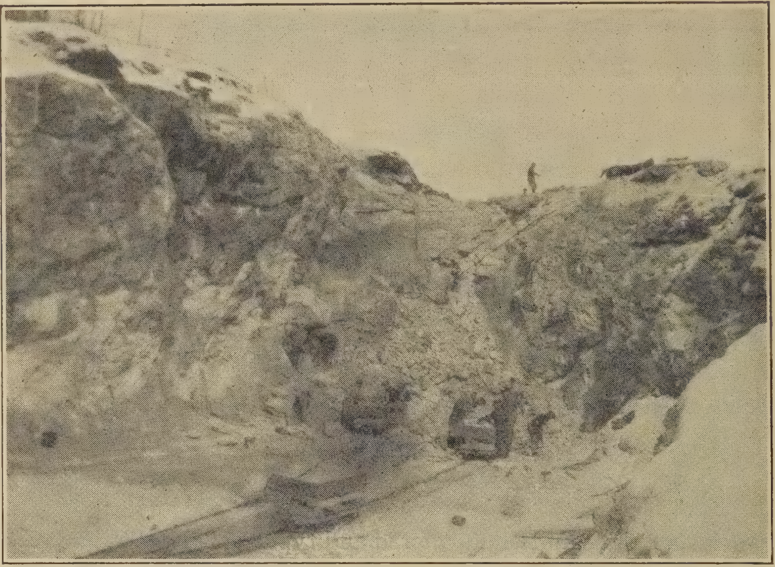

FIG. 2.—Face of quarry, 1921–22.

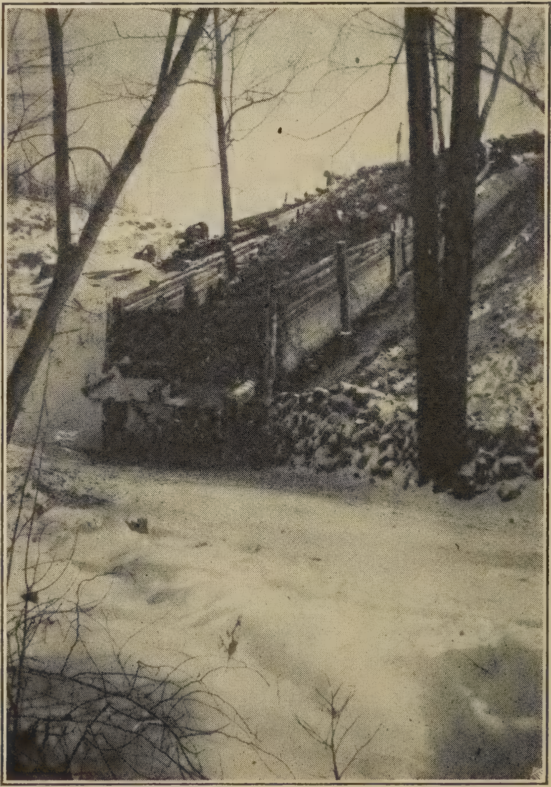

FIG. 3.—Ore bin at mine.

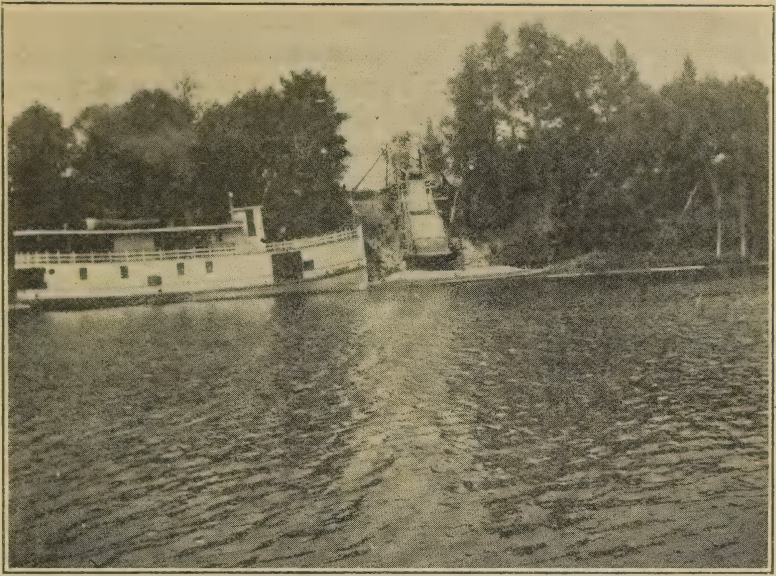

FIG. 4.—Summer transportation on Lièvre River.

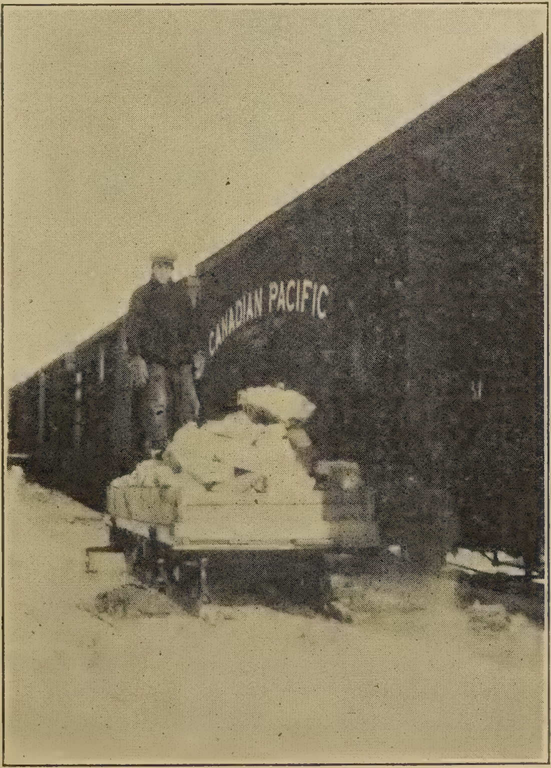

FIG. 5.—Winter transportation.

down stream to the railroad siding at Buckingham. Here a suitable derrick is provided for loading the railroad cars or placing in stock pile. The piling ground is covered with a plank platform so that from the time the feldspar is loaded out from the quarry to the time it is shipped every effort is made to keep it scrupulously clean.

The fine material or waste material from the quarry finds a ready market as a stucco dash giving a rich cream to buff tone to a building. The quartz is sold locally for use as a flux in the electric furnace manufacture of phosphorus and its compounds.

Hence the Derry quarry stands unique in having an abundance of the highest grade feldspar, a minimum of accessory minerals, and no waste material.

O'Brien and Fowler
Ottawa, Canada

SOME EXPERIMENTS ON THE FIRECRACKING OF TERRA COTTA[1]

By E. C. Hill

ABSTRACT

Firecracking occurs on terra cotta under certain conditions and is characterized by the appearance of sharp, hair-line cracks extending into the body. The experiments were made by firing large typical pieces of terra cotta made from various clays and grogs and cooling them at different rates. The tendency to firecrack was observed after weathering. The absorption, porosity and transverse strength of the various bodies were determined.

Rate of Cooling.—All bodies similar to those used in practice showed a tendency to firecrack when cooled rapidly and all were free from cracks when cooled slowly. The rate of cooling has a much greater effect on the tendency to firecrack than the composition or physical properties of the body.

Effect of Clay.—Three of the four sandy clays showed a decided tendency to firecrack, due to the difference in the expansion and contraction behavior of sand and clay in heating and cooling. The sandy clays showed more tendency to firecrack than the non-sandy, vitrifying clays. The tendency of a clay to develop firecracks in a body depends to a very large extent upon the character of the clay itself, regardless of the impurities it contains. The presence of sandy material and the character of the clay appear to have a much greater effect on the tendency to firecrack than the absorption, porosity or transverse strength of the body. No relation was found to exist in these experiments between the porosity and transverse strength of a body and its tendency to firecrack.

Effect of Grog.—The greatest tendency to firecrack was found on a body with all grog finer than 40-mesh, but a body with all grog coarser than 40-mesh did not appear to have much less tendency to firecrack than the average. Increase of grog reduced the tendency to firecrack. The kind or source of the grog used does not have as much effect on the tendency to firecrack as the size and amount. The kind of grog is of much less importance in this respect than the kind of clay.

Introduction

Definition of Firecracks.—The sharp, hair-line cracks that may appear on terra cotta under certain conditions are termed firecracks, cooling cracks or dunting. They are caused by contraction strains being set up in the body during the cooling. If these strains are severe the piece may be cracked when drawn from the kiln. If the strains are less severe, the cracking may not occur until a considerable time after the piece has been set in the building.

Firecracks Due to Strains.—Pieces set in the wall generally do not develop firecracks so readily as those placed in projecting courses and in exposed positions. When placed so that they catch the direct rays of the sun, they are subjected to an unequal heating nearly every day, with a subsequent cooling at night. If such pieces have had severe strains set up in them during the cooling of the kiln, they are likely to develop firecracks.

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[1] Read before the Terra Cotta Division, St. Louis meeting, February 28, 1922.

In some experiments made six years ago, some pieces were placed on the roof where they would be exposed to the weather. There were no failures whatever until during the third year, when a considerable number of the trials developed firecracks. It is possible, however, that even when cooled slowly, pieces may be of such size and shape and the body of such composition that they would be unable to withstand repeated expansion and contraction strains over long periods of time in service.

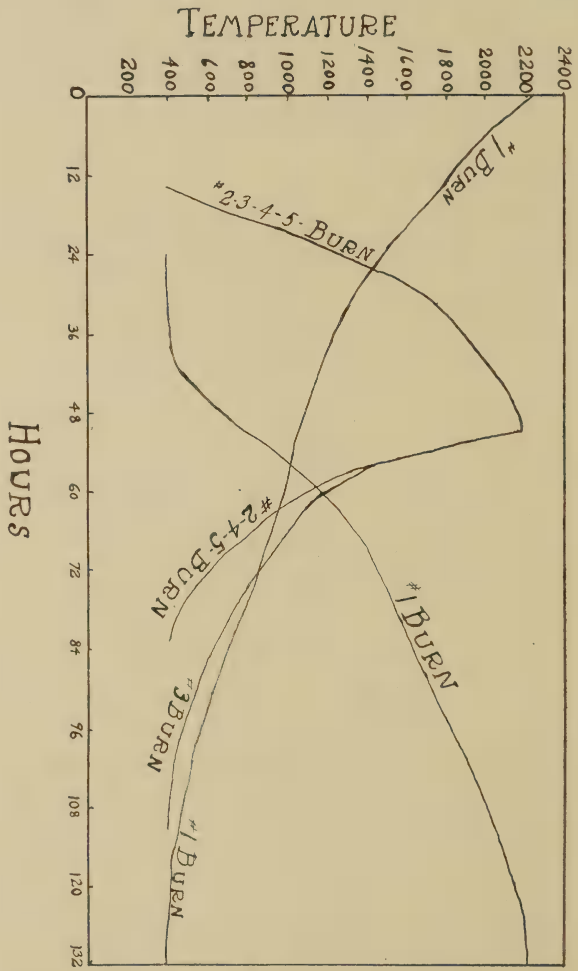


FIG. 1.

Too Rapid Cooling a Cause of Firecracking.—It is generally recognized that firecracking is due to too rapid cooling of the kilns and the customary procedure is to lengthen the cooling period. In periodic kilns, there is a considerable difference in the rate of cooling in different parts of the kiln. In firing terra cotta, where there is such a variety of sizes and shapes, the cooling period must be long enough to cool the largest pieces in the parts of the kiln where the cooling is the most rapid. The kilns used at the different plants vary in size from capacities of 15 to 100 tons so that if the cooling is not regulated, the time of cooling often varies 100%. There is no general practice regarding a safe cooling period and in practice it may be from 4 to 8 days.

While the effect of the rate of cooling on the tendency of bodies to firecrack is generally understood, there is a wide difference of opinion in regard to the effect of the composition and physical properties of the body. The experiments reported in this paper were made in an attempt to obtain some data on the effect of the composition and physical properties of the body, and to determine the relative importance of the composition, physical properties and rate of cooling.

Investigation

Methods.—The trials for firecracking were made in the form of pieces of a dentil molded course 24″ long, 10″ wide and 14″ deep, weighing about 115 lbs. Three trials of each body were fired in each burn, two being glazed and one coated with a vitrified slip. The bodies were prepared by grinding the clay and grog separately to pass a 16-mesh screen. One per cent barium carbonate was added to the clay. The clay and grog were mixed dry on the floor by hand-shoveling and pugged in a small pug mill. The pieces were pressed in the usual manner.

The trials for linear fire shrinkage were 7″ x $3^1/_2$″ x 2″ and the results given are the average of five.

The transverse strength trials were 8″ x $1^1/_4$″ x 1″ and the results given are the average of ten. These were broken on an Olsen Shot Transverse Strength Machine with a 6-inch span and the modulus of rupture calculated by the usual formula.

The absorption trials were about 2″ long and were obtained from the broken transverse strength trials. They were boiled in water for 2 hrs. and the absorption calculated by the usual formula. The porosity determinations were calculated by the Purdy formula.

Series I

Six bodies of widely different composition were used. All have two parts clay to one of grog. No. 1 is made of Campbell Red (N. J.) clay, which vitrifies at Cone 6 and vitrified porcelain (sanitary ware) grog. No. 2 is a mixture of terra cotta clays and the same grog. No. 3 has the same clay as No. 2 but has porous sagger grog. No. 4 is composed of a very sandy local clay, No. 5 Tennessee Ball clay, and No. 6 Georgia kaolin.

These bodies were fired to Cone 6 in three different burns. Burn No. 1 was made in a 40-ton terra cotta kiln with the regular ware and represents an average burn. The trials for shrinkage, absorption, etc., were fired in this burn and the results given in Table I.

Burn No. 2 was made in a test kiln of one and a half tons capacity. The cooling is regulated by the damper in the stack. The kiln was cooled as quickly as possible by opening the damper in the stack, drawing air through the fire holes and up around the muffle and out the stack, but without any direct opening into the muffle. The curves shown on the chart are the average of several made in these experiments, the first curve obtained being followed as closely as possible. A duplicate set of shrinkage, absorption, etc., trials were fired in this burn and the results were reasonably close to the No. 1 burn.

Burn No. 3 was made in the same kiln in the same manner as No. 2, except that, in cooling, when 1200°F was reached the damper in the stack was closed and the fire holes shut, so that the balance of the cooling would be at as slow a rate as possible with this kiln.

Results

SERIES I

CLAYS

No.		Per cent linear fire shrinkage	Per cent absorption	Per cent porosity	Modulus rupture no. sq. in.
1	Campbell Red	8.45	.42	.96	4422
2–3	Terra Cotta Mix	6.31	7.78	15.79	3362
4	Penna. Sandy	7.62	6.77	14.34	2002
5	Tennessee Ball	10.50	4.82	10.87	3610
6	Georgia Kaolin	7.91	15.79	27.34	1628

BODIES

No.		Per cent linear fire shrinkage	Per cent absorption	Per cent porosity	Modulus rupture no. sq. in.
1	Campbell Red-Vit. Porc.	5.71	4.79	10.19	2876
2	Terra Cotta-Vit. Porc.	4.43	10.33	20.43	2310
3	Terra Cotta-Sagger	2.51	14.90	27.56	1573
4	Penna. Sandy-Sagger	3.53	13.08	25.10	1350
5	Tennessee Ball-Sagger	5.34	13.62	26.00	1980
6	Georgia Kaolin-Sagger	3.22	18.47	32.91	1757

The trials for firecracking have been on a roof exposed to the weather for one year.

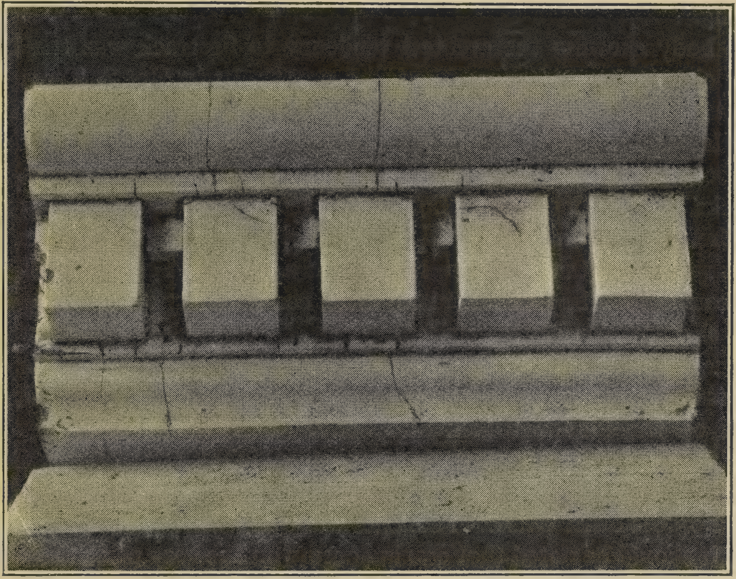
1. Campbell Red-vitrified porcelain. Burn No. 1, all O. K. Burn No. 2, one of three trials has two deep cracks. Burn No. 3, all O. K. Faint, fine-mesh crazing in wavy lines is starting to develop on some glaze trials in burns No. 2 and 3.

2. Terra Cotta mix-vitrified porcelain. Burn No. 1, O. K. Burn No. 2, all cracked. Burn No. 3, all cracked but less than burn No. 2.

3. Terra Cotta mix-sagger grog. Burn No. 1, O. K. Burn No. 2, all cracked. Burn No. 3, all cracked but less than burn No. 2.

4. Penna. Sandy clay-sagger grog. Burn No. 1, both glaze and slip are crazed. One of three trials cracked. Burn No. 2, all badly cracked and glazed trials badly crazed. Burn No. 3, all badly cracked and glazed trials badly crazed.

5. Tennessee Ball clay-sagger grog. The unglazed trial has several shrinkage cracks in wavy lines that extend into the body a short distance, but no sharp hair-line cracks characteristic of firecracks. The glazed trials are crazed and have a few slight shrinkage cracks, but no firecracks. In burns No. 2 and No. 3, the rapid firing has increased the shrinkage cracks greatly, so that the pieces are probably no stronger than if firecracked. The development of shrinkage cracks that extend deep into the body have probably prevented firecracks from developing. The glazed trials are badly crazed.



Photograph showing typical firecracking in these experiments.

6. Georgia kaolin-sagger grog. Burn No. 1, unglazed trial has a few slight shrinkage cracks. The glazed trials have no cracks of any kind, but one trial has severe shivering of the glaze. Burn No. 2, the trials have slight shrinkage cracks, but no firecracks. Burn No. 3, no firecracks. The unglazed trial has slight shrinkage cracks, but both glaze trials have none.

In firing the trials in the large kiln (burn No. 1) all the pieces were set against the muffle in the same part of the kiln, so that all received about the same treatment in heating and cooling. In the small kiln, burns Nos. 2 and 3, the pieces received about the same treatment in heating, but the cooling treatment, no doubt, varied considerably, depending upon their position in the kiln. Pieces of the same body were separated as much as possible so that the average treatment of the three trials were about the same.

All bodies were free from firecracking in burn No. 1, except one trial of the Penna. Sandy clay body. There was less cracking in the No. 3 burn than the No. 2 burn, but in only one case, that of the one trial of Campbell Red body, was the additional time of cooling sufficient to overcome the cracking.

The body showing the greatest tendency to firecrack was the Penna. Sandy clay body. After weathering a month, body No. 2, Terra Cotta mix-vitrified porcelain grog, had developed more cracks than No. 3, with the same clay and sagger grog, but after one year's weathering the difference is not so marked. For burn No. 3, the trials show about the same amount of cracks, but for burn No. 2, body No. 3 has less cracking. Body No. 1, with the vitrified Campbell Red clay and vitrified grog, has less cracking than any except the Georgia kaolin body. The Tennessee Ball clay body can hardly be considered in these comparisons on account of the severe shrinkage cracks developed.

Penna. Sandy clay body caused the greatest crazing in the glaze. The Tennessee Ball clay body also has severe crazing. Faint crazing has started on the Campbell Red clay body. The crazing is greater in all cases in the short burn with rapid cooling. One trial of the Georgia kaolin body shivered in the long burn, but no further shivering has developed on the other trials. This trial was shivered when drawn from the kiln. It should be noted that crazing occurs on the very plastic Tennessee Ball clay body and on the very sandy Penna. Sandy clay body, while shivering occurs on the porous Georgia kaolin body. Until further data are obtained on the effect of the body on the crazing and shivering behavior of this type of glaze (Bristol), the effect of the different kinds of clay in the body can not be predicted from the composition or physical properties.

Aside from the fact that practically all the bodies are free from firecracking when cooled as in burn No. 1 and all of the bodies similar to those used in practice firecracked when cool as in burns Nos. 2 and 3, no further information has been obtained in regard to the rate of cooling. In burn No. 2, it required 33 hrs. to cool to 400°F, and would probably require 12 hrs. more to cool down to the temperature at which the door is usually taken down, and air allowed to enter directly into the kiln, making a total cooling period of 45 hrs. In planning these experiments, it was thought that by cooling more slowly below 1200°F, some bodies might be cooled safely in this way, but no great difference was found between the two burns. It required 60 hrs. to cool to 400°F in burn No. 3, and with an additional 12 hrs. for cooling to the temperature at which the door could be taken down, would make a total of 72 hrs. In another burn, by closing the damper in the stack shortly after the firing was stopped, the cooling was prolonged 12 hrs., making a total of 84 hrs. Trials made from a body similar to the No. 3 developed firecracks in this burn. This burn gave the slowest rate of cooling possible in this kiln, without continuing the firing during the cooling period, which, no doubt, would produce very uneven temperatures inside the kiln. For this reason it was impossible to continue the experiments on the rate of cooling.

Burn No. 1 represents a typical firing and cooling curve for a 40-ton kiln with the thermo-couple at the muffle wall half-way up the kiln. The firing requires from 132 to 144 hrs. In the burn shown by the curve, the door was taken down after 168 hrs. (7 days). This represents a standard cooling period of $6^1/_2$ to 7 days. When stressed for time, the kilns have been cooled in $5^1/_2$ to 6 days without danger of firecracking as far as we can determine. When cooled in from $4^1/_2$ to 5 days, firecracking has developed in the past on large pieces after weathering for a considerable period, and to guard against this we have increased the standard cooling period to $6^1/_2$ or 7 days. In presenting this cooling curve, it must be borne in mind that the bottoms of these kilns cooled at a considerably greater rate than at the point where the temperature is recorded.

Experiments could be made with profit in shortening the time of cooling as shown by the curve for the No. 1 burn. The cooling could likely be more rapid for temperatures above 1200°F. The difficulty in shortening the cooling period comes from the fact that it requires such a long period of weathering to determine whether or not we are damaging the ware.

Series II

These experiments were made in the same manner as Series I, using 7 terra cotta clays and factory grog. Two parts of clay to one of grog were used. The bodies were fired to Cone 6 (burn No. 4) in the test kiln and cooled rapidly. The trials for absorption, strength, etc., were fired in a large kiln, similar to burn No. 1 in order to conform to the Series I trials. The trials for firecracking have been weathered nine months.

There is no crazing or shivering on any of the trials and no shrinkage cracks (wavy lines).

All trials are firecracked. Enterprise No. 30 developed considerably more cracks than the others. Russell Black clay has less cracks than the Enterprise but more than the remainder. The remaining five bodies are so nearly alike that no distinction can be drawn between them, except that the body with McDowell Buff clay has a trifle more cracks than the others.

Results

SERIES II

CLAYS

Body	Clay	Per cent residue 200-mesh	Per cent dry shrinkage	Per cent fire shrinkage	Per cent absorption	Per cent porosity	Modulus rupture lbs. per sq. in.
7	Crossley No. 1—N. J.	8.20	6.16	6.68	9.45	19.27	3226
8	Enterprise No. 30—N. J.	7.09	5.93	5.48	8.96	17.87	3095
9	Edgars No. 9—N. J.	.14	3.99	7.49	.09	.20	6130
10	Cursey Buff—Md.	1.12	5.78	7.26	1.02	2.12	4784
11	Cursey Blue—Md.	2.57	6.79	7.65	2.83	6.51	4701
12	McDowell Buff—Md.	1.16	5.73	7.98	.41	.61	6385
13	Russell Black—Md.	15.10	5.21	5.71	4.64	9.90	2882

BODIES

Body	Clay	Dry mod. rupture lbs. per sq. in.	Per cent fire shrinkage	Per cent absorption	Per cent porosity	Modulus rupture lbs. per sq. in.
7	Crossley No. 1—N. J.	151	2.77	16.14	29.65	1665
8	Enterprise No. 30—N. J.	117	2.53	15.62	28.91	1568
9	Edgar No. 9—N. J.	100	4.21	12.21	23.49	2287
10	Cursey Buff—Md.	158	3.87	11.19	21.99	2437
11	Cursey Blue—Md.	202	3.10	13.94	25.95	2004
12	McDowell Buff—Md.	154	4.03	11.06	21.53	2365
13	Russell Black—Md.	...	2.46	12.28	23.73	1860

All of the clays in this series, except the Russell clay, have been in use during the past two years, and some of their physical properties determined from different shipments. While the residue when washed on a 200-mesh screen can not be used as a value indicating the sandy nature of the clay, since the residue may contain other impurities and sand finer than 200-mesh, it does show to a limited extent something of the siliceous nature of the clay. The 8.2% residue on 200-mesh screen in the Crossley clay is somewhat high for this clay and contains some impurities other than sand. The residue of the Russell and Cursey Blue clay contained black organic matter in addition to sand. The Russell clay appears to be similar to the other Maryland clays, if it were not for the large amount of sand it contains. The Enterprise clay is considered more siliceous than the Crossley and has a lower dry strength. The other Maryland clays are rather plastic and tight-burning. The Edgar clay is free from sand, is tight-burning and has a low drying shrinkage and low, dry transverse strength.

In this series, two of the three sandy clays showed a decided tendency to firecrack. In Series I, the Penna. Sandy clay body developed more cracks than any other body tested in these experiments. It is evident that the effect of sandy material in a clay tends to produce firecracking, due to the difference in the expansion and contraction behavior of the sand and clay in heating and cooling.

In this series, the four tight-burning, non-sandy clays developed considerably less cracks than the open-burning sandy ones, Crossley excepted. In Series I, the tight-burning red clay body showed less cracking tendency than the others except the Georgia kaolin body, which is so porous that cracking could hardly be expected to develop. Nothing in these experiments indicates that the tight-burning clays tend to produce firecracking. The presence of sandy material in the clay is more likely to develop firecracking than the use of tight-burning clay. These tests did not include any open-burning, non-sandy clays. Had such been included, they might have shown less tendency to crack than the tight-burning non-sandy ones.

The tendency of the clay to develop firecracking depends to a large extent on the character of the clay itself regardless of impurities, and its behavior can not be predicted in advance. While sandy material increases the tendency to firecrack, its effect may be to a large extent offset by the character of the clay, so that the amount of sandy material a clay contains can not be used as an indicator of this tendency. Thus the Crossley clay, while sandy, does not have the same tendency to crack as the two other sandy clays used.

There does not seem to be any relation between the absorption, porosity or strength of the clays in these experiments and their tendency to firecrack. From the behavior of refractories, we know that the open, porous bodies withstand temperature changes better than the tight ones, and we would expect the bodies with high porosity to have less cracking than the ones with low porosity, but the presence of sandy material and the character of the clay seem to have a much greater effect on the cracking tendency than the absorption or porosity. In Series I, the vitrified red body with only 4.79% absorption and 10.19% porosity showed much less tendency to crack than the terra cotta body with 14.90% absorption and 27.56% porosity.

Series III

These experiments were made in the same manner as Series I and II. In Series III, the same clay was used for all bodies and different kinds of grog were used as shown in the table, Series III. The different grogs were prepared in the same manner by grinding in the dry pan and passing them over the same screen. The screen analyses of the various grog are shown in the table. The trials were fired in the test kiln to Cone 6 (burn No. 5). The trials for absorption, shrinkage, etc., were fired to Cone 6 in a burn similar to burn No. 1.

The trials have been weathered six months. So far, firecracks have not developed in this series as much as in the other two series, but cracks will likely develop further after weathering.

SERIES III

Body	Grog	Dry mod. rupture lbs. per sq. in.	Per cent fire shrinkage	Per cent absorption	Per cent porosity	Modulus rupture lbs. per sq. in.
	Clay (No Grog)	262	6.85	2.79	6.05	3528
14	Saggers	185	3.56	12.13	23.37	2345
15	Kiln Slabs	158	3.34	13.05	24.76	2058
16	Fire Brick	193	3.28	12.09	23.45	2187
17	Terra Cotta	180	3.98	11.70	22.50	2278
18	Vitrified Porcelain	186	4.26	8.87	17.75	2675
20	Factory Grog thru 40-mesh	202	3.69	10.75	20.78	2554
21	Factory Grog over 40-mesh	152	3.50	13.17	25.15	1829
22	Factory Grog 33%	168	3.79	12.68	24.14	2043
23	Factory Grog 40%	173	2.66	12.65	24.76	1875

Bodies 20–23: Grog 8 Saggers, 1 Fire Brick, 1 Terra Cotta

Clay Mix
22.5% Crossley No. 1
22.5% Enterprise No. 30
22.5% Cursey
22.5% McDowell
10.0% Edgar No. 9

GROG ANALYSES

No.	Grog	On 10	On 20	On 35	On 65	On 100	Thru 100
14	Saggers	.27	27.74	27.58	17.51	9.94	16.87
15	Kiln Slabs	.65	29.80	29.15	17.18	5.90	17.36
16	Fire Brick	.27	21.54	28.07	19.30	8.63	22.18
17	Terra Cotta	.34	19.21	23.81	18.90	11.18	26.65
18	Vitrified Porcelain	1.04	30.90	23.54	15.51	7.70	21.23
20	Factory thru 40	..	...	...	22.54	23.40	54.00
21	Factory over 40	1.04	40.40	40.32	13.65	1.04	3.56
22–23	Factory	.52	30.03	23.40	16.20	7.66	22.20

No. 19 contained grog from furnace slag, but the trials were badly overfired and swelled. This grog contained a considerable amount of iron which discolored the body. All of the bodies contained two parts clay to one of grog, except No. 23, which contained 40% grog.

No. 15, kiln slabs, and No. 23, with 40% factory grog, had two of three trials O. K.

No. 14, saggers, No. 21, factory grog over 40-mesh, and No. 22, factory grog, have two of three trials cracked. The remainder have all trials cracked. No. 16, fire brick, No. 17, terra cotta, and No. 18, vitrified porcelain, have about the same number of cracks, but No. 20, factory grog through 40-mesh, is much worse than any other of the series.

The bodies with kiln slabs and saggers have less cracking than the fire brick and terra cotta. This is due in part at least to the fact that the latter two have a higher proportion of grog finer than 100-mesh, as shown by the screen analyses. Increasing the amount of grog has reduced the cracking. The body with grog finer than 40-mesh has considerably more cracking than the others, but the body with the grog coarser than 40-mesh does not appear to be much better than the average. Vitrified porcelain grog does not show a marked tendency to produce cracking, although the trials have a little more than the average number of cracks.

None of the grogs used can be considered as being of a highly siliceous nature. Grog containing a considerable amount of coarse quartz grains would no doubt have shown a tendency to produce cracking. Considering only the grogs used in this series, and they are representative of ordinary sources of supply in the East, the kind of grog does not seem to be nearly as important as the size and amount. It is well known that a large amount of grog finer than 40-mesh will produce cracking in the body. If the supply of any kind of grog is uniform so that in grinding it gives about the same screen analyses, the source of grog does not appear to be of great importance on the tendency of the body to firecrack. The kind of grog is of much less importance in this respect than the kind of clay.

In presenting these experiments, particularly those in Series II and III, it is recognized that they can not be considered as absolutely confirming the conclusions that were drawn from them. Had nine trials of each body instead of three been used, we might have been able to differentiate more clearly between certain mixtures. This would have made it necessary to make three burns in the test kiln on each series instead of one, which would have introduced another variable in the experiments. Further weathering of the Series III trials may show a greater difference between some of the bodies than exists at present.

While the rate of cooling has a much greater effect on the tendency of the body to firecrack than the composition, the latter is of considerable importance. There is no doubt but that a change in the composition of the body could easily produce firecracking in practice without changing the rate of cooling, particularly if the rate is somewhat rapid. The degree of sensitiveness of the bodies of various compositions to firecrack when cooled at the same rate is an indication of their ability to withstand expansion and contraction strains in service, and a number of failures of free-standing terra cotta have no doubt been due largely to expansion and contraction strains. By selecting a body that shows the least tendency towards firecracking, and cooling the kilns slowly, so that the strains set up by the contraction of the piece during cooling are reduced to a minimum, we should have a body that would have the greatest ability to withstand contraction and expansion strains when placed in exposed positions.

There have been other failures of terra cotta, when, through defective jointing or unsatisfactory construction, the pieces have become saturated with moisture and been subjected to alternate freezing and thawing over long periods of time. When such pieces are glazed or coated with an impervious slip, so that the moisture can not escape, portions of the surface sometimes spall or break off. It has been suggested as a remedy for this condition, that a body with lower porosity and higher strength be used. This suggestion has been opposed by some, chiefly on the ground that such a body would have more tendency to firecrack and would not be so able to withstand expansion and contraction strains in service. These experiments indicate that in many cases the porosity could be lowered and the strength increased, without increasing the tendency to firecrack, by a simple substitution of clays.

These considerations seem to indicate the desirability of further and much more extensive experiments on the composition of the body and the tendency to firecrack.

Conkling-Armstrong Terra Cotta Co.
Philadelphia, Pa.

NEW DEVELOPMENTS IN OXYCHLORIDE STUCCO AND FLOORING[1]

By J. B. Shaw and G. A. Bole[2]

ABSTRACT

Substitution of Calcium for Magnesium Chloride.—Calcium chloride can be substituted for magnesium chloride only under special conditions. Calcium chloride solutions must be much more dilute than magnesium chloride. Less filler can be used with magnesium chloride. Mixtures of the two chlorides do not give as good cement as either separately.

Dolomite-Calcium Chloride Cements.—Tensile strength, volume change, weathering tests, specific gravity figures are given. Some good cements are found. Some of the cements have weathered for two years.

Dolomite-Magnesium Chloride Cements.—Tensile strength, volume change, weathering tests, specific gravity figures are given. Some excellent cements are reported equal to magnesite cements with equal MgO content.

Introduction

Magnesium oxychloride cement has been used to some extent since the middle of the last century, but in view of some of its remarkable qualities it is difficult to understand why it has not found a very much more extensive use than it has. Some of the excellent qualities which have been attributed to it are as follows:

Very high tensile strength.
Low specific gravity, making a cement of great strength with little weight.
It is capable of taking a high polish.
When mixed with appropriate filler, it has a very high resilience, making it comfortable for office floors, etc.
It is not slippery.
It can be applied in a thin coat over wood or cement without cracking.

A search for the cause of the restricted use of this material revealed two serious disadvantages, namely:

(*a*) High cost.
(*b*) Frequent failure of floors laid with the cement, by cracking, buckling and expansion.

Cost

The high cost of this cement is partly due to the fact that magnesite, from which it has been made, occurs only in restricted areas far removed

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[1] Received April 3, 1922.

[2] Title covering this work was given in the program of the American Ceramic Society in February 1919, much of the work having been done prior to that date, but for various reasons the material was not put into proper shape for publication until this time.

from the centers of consumption. The fact that the material has failed frequently, rendering it necessary to do the work a second time, compelled those selling it to demand a high margin of profit to ensure them against loss. These two factors have combined to keep the cost of this material so high as to restrict its use.

The prestige of this cement was greatly damaged during the latter part of the last century by certain unscrupulous manufacturers who, without making sufficient preliminary experiments to learn how properly to make it or whether it would survive under exposure to weather, used it for building blocks and built houses of them. The material crumbled away in a few years and magnesium oxychloride cement has since labored under the disadvantage of this reputation.

This paper contains some of the results of an effort to find a method of utilizing the excellent qualities of this cement by overcoming the disadvantage under which it is laboring.

Reducing Cost

Source of MgO.—As stated above, magnesites have been the only source of caustic magnesia for the cement. This is, and must of necessity remain, an expensive material.

Dolomitic limestones are very widely distributed, occurring in large quantities close to the centers of industry. The only difference, chemically, between most magnesites and dolomites is the ratio in which the constituents occur. They contain practically the same ingredients. Therefore because of its large production and easy accessibility to the centers of consumption, substitution of dolomite for magnesite would result in very material reduction of first cost of the material.

Chloride.—Calcium chloride, being a by-product from chemical processes, and not having found a very extensive use, can be obtained at very much lower cost than magnesium chloride. This substitution would result in a further reduction in cost of the finished product. Barium chloride may be used.

While it seems likely that these two substitutions would reduce the cost of the material to a point where it could be widely used, such reduction would be useless unless the quality of the material could be so controlled as to give a uniformly safe product. The results of preliminary experiments along these lines were encouraging.

The oxide of magnesia exists in two forms, the light caustic oxide (sp. gr. 3.0) and the dead burned oxide (sp. gr. 3.8). The caustic oxide is obtained by calcining compounds containing magnesium carbonate at low temperature. The dead burnt oxide is obtained by heating at high temperature, or for a long period at medium temperature. The caustic oxide will hydrate slowly with very little evolution of heat. The dead burnt oxide will not hydrate. The caustic oxide is the form used in making oxychloride cement. The dead burnt is used for refractories.

The first question arising in considering the use of dolomite as a source of MgO is the influence of the carbonate of lime.

1. Will the presence of calcium oxide, resulting from calcining at too high a temperature, be injurious to oxychloride cement?

2. Is it possible commercially to calcine the dolomite so as to decompose the $MgCO_3$ to form caustic MgO and leave the $CaCO_3$ undecomposed?

3. Will the amount of MgO in such a limestone be sufficient to give good strong cement when diluted with the unavoidable $CaCO_3$ in the original rock?

Preliminary Experiments

The Dolomite.—In an endeavor to answer these questions a dolomitic limestone of massive form was selected having the following composition before calcining:

$CaCO_3$	55.83
$MgCO_3$	43.37
SiO_2	.14
FeO_2 and Al_2O_3	.14
H_2O organic	.52
	100.00

Magnesite.—California magnesite containing 98% $MgCO_3$ was calcined at 1000° C and tested to compare with the dolomites.

Calcining.—Fifty pounds of the rock were crushed to half-inch size and calcined in a covered sagger in a small updraft gas kiln. Thermo-couple was placed just over the surface of the dolomite.

Sample *A* was raised to 650°C in three hours and temperature held between 650°C and 700°C for three hours.

Sample *B* was raised to 770°C in three hours and temperature held between 770°C and 800°C for three hours.

Properties of Calcined Material.—Sample *A* was unchanged in appearance; color and hardness being about the same as the original rock.

Sample *B* had changed from the gray of the original rock to practically white. It was still hard but distinctly more brittle than the original rock.

Grinding.—The calcined material was ground dry in a ball mill. *A* ground slowly but left mill and pebbles clean. *B* ground somewhat more rapidly than *A* but coated the sides of the mill and pebbles. It has been noted that some magnesite calcined at 800°C to 1000° C sticks to the sides of mill and pebbles, or, in other words, balls up in the mill.

The screen analysis after grinding was as follows:

	A	B
On 100	1%	5%
Through 100 on 150	20	24
Through 150 on 200	15	15
Through 200	64	56

Chemical Tests.—The chemical tests for determining what carbonates and what oxides were present in the calcined material and in what proportion, were carried out by the method outlined by G. A. Bole[1] for direct determination of CO_2, also using the ammonium chloride method for active lime.

Below are given dissociation temperatures obtained on these materials.

Magnesite	470°C	Temperature at which the pressure of the CO_2 becomes atmospheric all at approximately 730° mm. Hg
Calcium carbonate	885°	
Mixture $MgCO_3$ and $CaCO_3$	470°	
†Raw dolomite	470°	

† Later investigations on many dolomites have proven this relation to hold for some dolomites only.

Determination of MgO, CaO, $MgCO_3$ and $CaCO_3$ in Calcined Material.—Total CO_2 was determined by blasting weighed sample. The CO_2 in $MgCO_3$ was determined by heating weighed sample at 700°C in an atmosphere of CO_2 until evolution of gas ceased and measuring the loss by the above-mentioned method, CO_2 and $CaCO_3$ were found by difference.

Results

		A (calcined at 650–700)	B (calcined at 770–800)
Total CO_2 lost by blasting		36.50%	26.50%
CO_2 lost by heating at 700°C		1.67	0.00
Calculated results	$MgCO_3$	4.5	0.0
	$CaCO_3$	70.0	60.0
	CaO	0.0	17.5
	MgO	25.5	22.5

The ammonium chloride method for free lime gave (*A*) 0.50% and (*B*) 18.2% of free lime, respectively.

The difference in CaO content indicates that a part of Sample *B* must have reached a sufficiently high temperature to decompose considerable quantity of $CaCO_3$. The effect of this free lime on the results in the physical tests is very evident.

Heat Evolved during Hydration.—This was determined by mixing 50 gr. of calcined powder with 25 cc. of water and inserting a thermometer in the mass. The method is admittedly crude and only indicates comparative values.

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[1] Bole and Shaw, *Trans. Am. Ceram. Soc.*, **17**, 125 (1915).

A calcined 650°–700° } no rise in temperature.

B calcined 700°–800° } 11° rise in temperature.

Magnesite.—Calcined 1000°C } no rise in temperature.

Presence of CaO in *B* is clearly indicated by the rise in temperature.

Oxychloride Cements.—The calcium chloride used in making up the solutions showed the following analysis:

$CaCl_2$	95.00
$NaCl_2$	1.44
H_2O and organic matter	3.40

The solutions were made up to 20° and 25° Baumé and kept in stoppered bottles.

Standard Ottawa sand was used.

The sawdust was fine (80-mesh) and dry.

The rule adopted for making up the cements was to follow industrial practice, by adding enough solution to make all the cements up to the same consistency as far as possible. Each mix was made up to such a consistency that it would just stand without flowing. The results obtained showed this to be a mistake as the amount of solution varied greatly, making large differences in the ratio of oxide to chloride and hence detracting from the value of the data obtained because of difficulty in interpretation. Later experiments show the results obtained by varying the ratio between MgO and chloride.

Time of Setting.—Cements made with calcium chloride are slower setting than those made with magnesium chloride.

Much free calcium oxide seems fatal to the cements. Sample *B* showed no setting in 24 hours and even after two weeks was soft. When magnesium chloride was added to this sample, efflorescence was distinctly evident in ten hours. The white scum then started continued to collect for weeks. Qualitative tests showed these crystals deposited on the surface to be calcium chloride.

The reaction producing this result is probably as follows:

$$CaO + MgCl_2 + H_2O = Mg(OH_2) + CaCl_2$$

No efflorescence was noticed at any time on Sample *A* or the calcined magnesite, whether made up from magnesium chloride or calcium chloride.

Constancy in Volume.—Constancy in volume was roughly determined by laying pats of the cement on glass plates, noting cracking and measuring linear shrinkage of test bars.

A—Every cement made from this sample adheres firmly to glass plates. No cracking was noted in any trials and no measurable shrinkage.

B—Decided shrinkage. No adherence to glass plate. Not hard.

Magnesite.—All trials made up from neat magnesite show some shrinkage. An important point noted is that the neat magnesite trials made up with calcium chloride show less shrinkage than those made up with magnesium chloride.

Neat MgO with $MgCl_2$ sets very rapidly and attains great hardness but it cracks badly. Neat MgO with $CaCl_2$ gives the strongest cement made, though it sets somewhat more slowly than MgO with $MgCl_2$.

Magnesite-sand-$CaCl_2$ mixture adheres to glass plates, shows no crack and no measurable shrinkage.

Specific Gravity.—Only a few determinations have been made:

		Sp. gr.	Per cu. ft.
(C-1)	Magnesite and $MgCl_2$	2.05	128
(A-1)	Dolomite and $MgCl_2$	1.99	124
(C-5)	Magnesite and $CaCl_2$	1.87	117
(A-5)	Dolomite and $CaCl_2$	1.79	112

Sawdust is frequently used in this cement, making a very light product.

Tensile Strength.—The following tables show the results obtained on tensile strength. The briquettes were made in standard cement moulds and in making them the specifications of A. S. T. M. were followed except for the consistency of the material as above stated.

DATA SHEET

Oxychloride Cement

Using Dolomite as Source of MgO

		Chloride				Tensile strength lbs. per sq. inch	
No.	Filler		Per cent[1]	Sp. gr. sol. deg. Baumé	C. c. sol. per 100 gr. mix	14 days	28 days
A-1	$CaCO_3$	$MgCl_2$	54.6	25	36	540	620
A-3	$CaCO_3$	$MgCl_2$	35.9	20	32	590	720
A-5	$CaCO_3$	$CaCl_2$	48.7	25	32	80	165
A-7	$CaCO_3$	$CaCl_2$	35.9	20	32	92	125
A-9	$CaCO_3$	($MgCl_2$) ($CaCl_2$)	(24.4) (24.4)	25	32	345	530
A-11	$CaCO_3$	($CaCl_2$)	(18.0) (18.0)	20	32	125	295
A-2	($CaCO_3$) (Sawdust)	$MgCl_2$	105.0	25	52	255	625
A-4	(Sawdust)	$MgCl_2$	44.5	20	32	475	625
A-8	(Sawdust)	$CaCl_2$	84.0	20	60	45	30
A-10	(Sawdust)	($MgCl_2$) ($CaCl_2$)	(48.0) (48.0)	25	51	190	213
A-12	(Sawdust)	($CaCl_2$)	(39.0) (39.0)	20	56	40	75

[1] Per cent figures on basis of 100 MgO, that is, 54.6% $MgCl_2$ equals 54.6 % of the MgO in the mix. Where sawdust is given, 20% by weight of mix was used.

DATA SHEET

Oxychloride Cement
Using Magnesite as Source of MgO

		Chloride				Tensile strength lbs. per sq. inch	
No.	Filler		Per cent[1]	Sp. gr. sol. deg. Baumé	C. c. sol. per 100 gr. mix	14 days	28 days
C-1	None	$MgCl_2$	18.0	25	60	105	60
C-3	None	$MgCl_2$	9.7	20	44	140	300
C-5	None	$CaCl_2$	16.6	25	52	610	1242
C-7	None	$CaCl_2$	11.0	20	50	677	556
C-9	None	($MgCl_2$)	(7.5)				
		($CaCl_2$)	(7.5)	25	50	383	902
C-11	None	($CaCl_2$)	(5.8)				
			(5.8)	20	52	540	665
C-2	Sand	$MgCl_2$	21.7	25	19	650	650
C-4	Sand	$MgCl_2$	13.4	20	16	555	610
C-8	Sand	$CaCl_2$	15.1	20	18	333	358
C-12	Sand	($MgCl_2$)	(7.5)				
		($CaCl_2$)	(7.5)	20	18	347	420

[1] Per cent figured on basis of 100 MgO, that is, 18.0% $MgCl_2$ equals 18.0% of the MgO in the mix. Where sand is given, 75% by weight of the mix is used.

No data on *B* are given in the table since no cements having any strength were obtained from it.

The high shrinkage of the neat magnesite trials is shown to have produced weak briquettes, probably due to cracks, some of which were plainly visible.

While $CaCl_2$ solution has produced the best strength with neat magnesite, the $MgCl_2$ solution gives best results when sand is added.

In the dolomite *A*, the $CaCl_2$ briquette shows tensile strength decidedly lower than the magnesite. (Later results have shown that the $CaCl_2$ solution used here was too high in sp. gr., better results being obtained with sp. gr. around 12 to 14 Bé.)

The mixtures of dolomite and $CaCl_2$ are much softer than $MgCl_2$-dolomite mixtures but the magnesite-$CaCl_2$ trials are as hard as the magnesite-$MgCl_2$ after 28 days. No explanation of this apparent inconsistency has been found.

A study of the table would seem to indicate that the following conclusions would be borne out by experience:

1. Calcined magnesite must be diluted with some coarse aggregate to give satisfactory cement with $MgCl_2$.
2. Calcium chloride can be successfully used to give strong cements with calcined magnesite.
3. Cements obtained with dolomite and $MgCl_2$ are as good as any obtained with magnesite with equal MgO content and $MgCl_2$.
4. Both dolomite and magnesite give cements of higher tensile strength than Portland cement.

The results obtained in these preliminary experiments indicated that this line of endeavor was well worth further pursuit. Three of the original questions which these experiments were designed to investigate have been answered, namely:

1. Free CaO resulting from overburning dolomite is decidedly injurious to oxychloride cement.
2. Dolomite does contain sufficient MgO to give a good cement when properly calcined.
3. Calcium chloride can be used to replace magnesium chloride only under proper conditions.

Calcining Dolomite.—One question has not been answered by these experiments, that is, as to whether dolomite can be calcined commercially so as to give a uniform product. An extensive investigation of this point was made and successful results have been obtained on commercial scale. This will be the subject of a separate paper. It may be said here that it was found impossible to burn dolomites properly under ordinary conditions of calcining these materials. A process was developed in which all conditions, especially temperature and pressure, were carefully controlled and by which successful results were obtained repeatedly on ton lots of dolomite.

Properties of Stucco and Flooring

A further study of this subject* was made by selecting different dolomites, studying their structure and properties and making tile, laying them on wood in much the same manner as floors are laid of this cement.

Tests were made to determine the effect of:

Fineness of grinding.
Temperature of cement during setting.
Humidity of the atmosphere during setting.
Strength of chloride solution.
Different kinds of coarse aggregate.
Expansion.
Weathering of finished product.

Fineness of Grinding.—In general fine ground material gives highest tensile strength. Dolomite-magnesium chloride mixtures show the following tensile strength in 7 days:

	200-mesh	100-mesh	On 100-mesh
	780	700	450
	750	680	490
	740	610	440
Average	760	660	460

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* Much of this work was done in the laboratory of the Solvay Process Company in coöperation with the writers.

Our experience has been, however, that too finely ground materials are more likely to crack in setting than those not so finely ground.

Temperature during Setting.—Tile made from dolomite and $MgCl_2$ solution 18° Bé. held at 80°F set hard in two hours and developed tensile strength of 550 lbs. per sq. in. in two days. Ordinarily it requires 3 to 5 hours for final set.

Humidity during Setting.—Test pieces placed in a damp box where relative humidity was high set very slowly, developing only 50 lbs. per sq. in. in tensile strength in 7 days. Did not set after taking from the box.

Weathering.—Briquettes made from coarsely ground dolomite-calcium chloride mixtures show following tensile strength:

	7 days	14 days	2 years' exposure to weather
13° Bé.	180 lbs.	210 lbs.	390 lbs.
13° Bé.	150	200	430
14° Bé.	160	185	420

This indicates that this material does not deteriorate badly in weather.

Tile made from these same mixtures have been exposed to the weather since August 1919 and are in good state of preservation.

Data Sheet

Oxychloride Cements
Using Dolomite as Source of MgO
Cement Tile Laid $^1/_2$″ Thick on Wood

		MgO	Calcium chloride sol.				
No.		Per cent fineness	Per cent free CaO	Sp. gr. deg. Bé.	C. c. per 100 gr. mix	Per cent	Results
10	25	7% on 100	1.0	14.3	46	30.9	Cracked but hard
14*a*	25	7% on 100	1.0	14.3	45	32	Shrinks in setting
17	27.5	100	1.0	14.3	38	19.9	Cracked, not trowelled
17*a*	27.5	7% on 100	1.0	14.3	38	19.9	Cracked, not trowelled
18	27.5	7% on 100	1.0	14.3	36	18.5	Good
19	27.5	7% on 100	1.0	14.3	31	19.9	Good
19*a*	27.5	200	1.0	14.3	31	19.9	Good
20	27.5	100	1.0	14.3	31	19.9	Good
20*a*	27.5	7% on 100	1.0	14.3	31	19.9	Good
22	27.5	7% on 100	1.0	13	31	18	Good
22*a*	27.5	7% on 100	1.0	12	31	16.6	Good
26	27.7	7% on 100	1.0	10	31	13.3	Good
26*a*	27.7	7% on 100	1.0	11	31	14.9	Good
27	27.7	7% on 100	1.0	12	31	16.4	Good
27*a*	27.7	7% on 100	1.0	13	31	18.0	Good
28	27.7	7% on 100	1.0	18	31	24.9	Sets slowly
28*a*	27.7	7% on 100	1.0	20	31	28.7	Sets very slowly, poor tile

The data in the above table indicate that calcium chloride with properly burned dolomite will give good cement.

Good results have been obtained with the tile containing from 13–25% calcium chloride (percentage based on MgO present).

When magnesium chloride is used, the percentage of chloride runs higher.

Time of Setting.—These calcium chloride cements are almost invariably slower setting than when magnesium chloride is used.

	Initial set	Final set
Dolomite-$CaCl_2$	40 min. to 1 hour	4 to 7 hours
Dolomite-$MgCl_2$	30 min. to 50 min.	3 to 5 hours

Fineness of the material and strength of chloride solution are important factors in determining time of set.

Fine material sets more rapidly.

Low sp. gr. calcium chloride solution promotes rapid setting.

Stucco.—If this material is to be used for stucco, it is essential that it withstand weathering; some of the data given above indicates that it will stand weathering if properly made. A very thorough investigation is necessary to determine many points as to how to improve its weather resistance. Other investigators, notably The Dow Chemical Company, are working on this problem and results they have obtained are worthy of note. They have investigated many brands of commercial cements as well as some which we have produced from dolomite. Incidentally it may be said that the dolomite product stands in the front rank. Their test shows the product made from dolomite compares favorably with the commercial stucco material on the market, in its ability to stand up under weathering test, which consists of making test pieces, allow them to set 14 days, spray them with water 24 hours continuously, dry 24 hours, spray 24 hours and dry, repeating for three successive days, then determine modulus of rupture (wet) and after allowing to dry 2 days.

DATA.—TESTS MADE BY THE DOW CHEMICAL CO. MATERIAL CALCINED BY SHAW AND BOLE

Analysis of Calcine Material

	Canadian magnesite	Gouvenour dolomite	
		A-1	A-2
Loss on ignition	19.50	31.70	33.95
SiO_2	1.30	1.53	.37
R_2O_3	1.25	.97	.22
CaO	12.72	34.50	37.85
MgO	66.60	27.20	27.80

Stucco mix, using $MgCl_2$ solution 22°Bé.

Canadian Magnesite	1	Dolomite A-1	2.5	Dolomite A-2	2.5
Ground Flint	2	Ground Flint	1.0	Ground Flint	1.0
Sand	5	Sand	4.5	Sand	4.5

	Tensile strength		
	1 day	3 days	7 days
Canadian Magnesite body	408	402	400
A-1 Dolomite body	..	..	467
A-2 Dolomite body	258	428	488

		Per cent change in length		
		1 day	3 days	7 days
Canadian Magnesite Body	(normal air).....	−.02	−.02	−.03
	(wet air).........	+.006	−.004	+.025
A-1 Dolomite Body	(normal air)......	+.18	+.28	+.31
A-2 Dolomite Body	(normal air)......	+.04	+.06	+.06
	(wet air).........	+.07	+.13	+.14

− Indicates contraction. + Indicates expansion.

		Water resistance			
		Dry	Wet	Recovered	Per cent recovered
Modulus of Rupture	Canadian Magnesite...	1614	702	1605	98.0
	A-1..................	1596	768	969	60.7
	A-2..................	1890	990	1458	77.1

Recovery of 50% or more considered good.

These tests show that high strength of dry test piece does not indicate high resistance to weather and that fine aggregate promotes weather resistance. The dolomite cement has this advantage and probably owes its high weather resistance to it. Tests which they made on Canadian magnesite shown in the table gave exceptional results.

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MICROSCOPIC STUDY OF GROUND COAT AND COVER COAT ENAMEL REACTIONS[1]

By E. E. Geisinger

ABSTRACT

A study of ground coat and cover coat enamel reactions showing that the degree of susceptibility of enamels to furnace gases is easily classified by cross-section examination under the microscope. The excess intermingling of the ground and cover coats and interaction between ingredients can be determined. Lack of firing range of the two coats is easily noted. The tendency of an excess gasifying of the enamel on the ware is seen. The high viscosity of enamels which do not allow the ready escape of occluded air and gases, thereby forming large bubbles and resulting weak structure, is studied. Results of overfiring and underfiring are summarized.

Introduction

We who are working with glass enamels are studying each new as well as old glass combination from every possible angle, considering such points as raw material cost, smelting properties, gravity and slip properties, and when applying to the ware, such properties as softening temperature, flowing and finishing temperature, burning range, etc. The color, gloss and general appearance are probably next registered, and finally we use innumerable schemes of comparative tests of durability to physical abuse as well as general corrosion and acid resistivity tests. It is important that we determine whether this new combination will be a constant or too frequent offender in regard to fishscaling, shivering or other poor results caused by factory conditions which are at certain periods unavoidably not ideal or even good. If the importance and help of a microscopic study of enamels are realized by our fellow workers, after hearing this paper and seeing the series of photos, the purpose will have been fulfilled.

The Microscope in the Factory

The steel is studied and controlled from a purely metallurgical standpoint, using mostly the microscope. As our work is all on heavy steel plate, not being less than $^5/_{16}''$, and our method of cleaning is the sandblast, we are not interested in the pickling properties of steel. The microscope has been found invaluable in showing extreme high or low carbon content, slag and oxide occlusions together with any other rolling defects. However, the texture of the sandblasted steel surface as it leaves the blast is examined with a low power double lens, for it has been proved to us by experience that a so-called open rough surface is best for enameling on steel. We have found that the tendency of steel working, annealing or rusting is to give an open ragged surface, which in turn helps to inhibit the fishscaling trouble. Messrs. Danielson and Souder touched very close to a key-note, we believe, when they advanced the steel surface problem relative to fishscaling.

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[1] Read before the Enamels Division, St. Louis meeting, February 28, 1922.

Cross-Section Study of Enamel

Description of Method Used.—Enamel surfaces have been studied under the microscope as suggested by Mr. E. P. Poste in *Trans. Am. Ceram. Soc.*, **19,** 146 (1917) and this rather prompted us to study our enamels in cross-section. It has since been found that microscopic examination of the surface is more deceiving in many instances, for the temperature of the furnace will fine out the bubbles on the very top surface, leaving a very bad condition underneath. The cross-section views have told much more as to the true condition of the glass on the steel. If the problem is to examine the enamel from factory production, a chip is removed with the chisel, which is very easy with this thickness of steel. In the study of new enamels, however, flat rectangular test pieces are used and the enamel is applied to the very edge. A hammer blow on a small chisel, holding it close to the edge of the test piece and directing the chips out, will generally remove a few pieces of enamel quite clean to the steel or at least only leaving a little ground coat on the steel. It is found convenient and almost necessary to hold a cloth over the test piece so as to catch the small chips. Take the chips, and carefully break them between your finger tips until you get a break which presents a medium smooth surface. It is not necessary to be so careful about this break being even unless one intends to take a microphotograph, for differences in focus can be taken care of while examining. Much more can be seen by examining the real specimens, which of course is the case with anything that is not polished absolutely flat. By using a drop of sealing wax on a regular glass slide, the mount is easily made by just warming the spot of wax and imbedding your chip on edge, taking care to level the top edges in one geometric plane. An arc lamp is used with direct impinging condensed light, placing the ray so that it hits the chip's top edge surface at an oblique angle. A study at thirty-five to one hundred magnifications is generally sufficient, and will tell one very much as to what has happened to his glass while firing on the steel.

Example Series—Microphotos—Results

The following ground coat was used in the series, as the study was to be essentially one of two coat ware:

Ground Coat "A"

Silica	150
Feldspar	320
Borax	360
Soda	70
Cobalt Oxide	30
Manganese Oxide	70
	1000 Raw batch weight.

Add 10% raw silica and 5% clay at mill.

TABLE I

BLUE COVER ENAMELS—RAW BATCH WEIGHTS

Enamel	B1 −	B1 +	B2 −	B2 +	B3 −	B3 +	B4 −	B4 +	B5 −	B5 +
Silica	200	200	200	200	200	200	200	200	200	200
Feldspar	400	400	400	400	400	400	400	400	400	400
Soda	300	300	300	300	300	300	300	300	300	300
Borax	70	70	70	70	70	70	70	70	70	70
Cobalt Oxide	10	10	10	10	10	10	10	10	10	10
Manganese Oxide	10	100	. .	. .	. .	. .	. .	. .	. .	. .
Cryolite	. .	. .	10	100	. .	. .	. .	. .	. .	. .
Zinc Oxide	. .	. .	. .	. .	10	100	. .	. .	. .	. .
Barium Carbonate	. .	. .	. .	. .	. .	. .	10	100	. .	. .
Kalkspar	. .	. .	. .	. .	. .	. .	. .	. .	10	100
Litharge	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Zirconium Oxide	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Titanium Oxide	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Nickel Oxide	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Black Iron Oxide	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
(*a*) Results: Correct Fire	Good	Good	Good	Fair Porous	Good	Good	Good	Good	Good	Good
(*b*) Reducing Atmosphere	Blister Shiver	Porous	Porous	Some Fishscaled	Fishscaled	One Fishscaled	Two Fishscaled	Fair	Fishscaled	Shivered
(*c*) Overfired	Blister Shiver Porous	Blister Shiver	Porous Shiver	Fishscaled	Fishscaled	Shivered	Blistered	Shivered	Fair	Fishscaled
(*d*) Underfired	Dull O. K.	Dull O. K.	Good	Dull Good	Dull Good	Dull Good	Dull Good	Dull Good	Dull Good	Dull Good
Remarks:				"*b*" and "*c*" Reaction						

TABLE I (Continued)

BLUE COVER ENAMELS—RAW BATCH WEIGHTS

Enamel	B6 −	B6 +	B7 −	B7 +	B8 −	B8 +	B9 −	B9 +	B10 −	B10 +
Silica	200	200	200	110	200	110	200	200	200	200
Feldspar	400	400	400	400	400	400	400	400	400	400
Soda	300	300	300	300	300	300	300	300	300	300
Borax	70	70	70	70	70	70	70	70	70	70
Cobalt Oxide	10	10	10	10	10	10	10	10	10	10
Manganese Oxide	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Cryolite	. .	. .	. .	. .	. . .	. .	. .	. .	. .	. .
Zinc Oxide	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Barium Carbonate	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Kalkspar	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Litharge	10	100	. .	. .	. .	. .	. .	. .	. .	. .
Zirconium Oxide	. .	. .	10	100	. .	. .	. .	. .	. .	. .
Titanium Oxide	. .	. .	. .	. .	10	100	. .	. .	. .	. .
Nickel Oxide	. .	. .	. .	. .	. .	. .	10	100	. .	. .
Black Iron Oxide	. .	. .	. .	. .	. .	. .	. .	. .	10	100
(*a*) Results: Correct Fire	Shivered	Good	Good	Good	Good	Good	Good	Good	Good	Good
(*b*) Reducing Atmosphere	Shivered	Shivered	Fish-scaled	Shivered	Fair	Porous	Shivered	Shivered	Fishscaled	Good
(*c*) Overfired	Blistered Poor	Shivered	Shivered	Fair	Porous	Shivered	Shivered	Fair	Shivered	Good
(*d*) Underfired	Dull Good	Good	Dull Good	Dull Good	Dull Good	Good	Dull Good	Dull Good	Dull Fair	Good
Remarks:	"*b*" and "*c*" Reaction	"*b*" and "*c*" Reaction				"*b*" and "*c*" Reaction		"*b*" Reaction		

Test pieces were used with the following dimensions: 2″ x 4″ x $^5/_{16}$″ thick, and all were cut from one plate of steel. A microphoto of the steel used is shown in Fig. 1.

All cover coats were milled with 3% of Johnson Porter clay. Both ground coat and cover coats were sprayed on the steel pieces. Table I gives the cover coat ingredients, and short notes as to the results of the test pieces after standing two months. The first series of twenty enamels is an attempt to compare the effect of varying one metallic oxide, which we will call the "variable," being added in a minimum quantity of 10 parts and a maximum quantity of 100 parts. In each case the cover coat is a cobalt-blue enamel, and the enamels were fired in a small gas furnace under the four conditions as tabulated, *viz.:* (*a*) Correct Fire. This meaning a temperature of 1700 degrees F and a firing period of just what my experience and judgment would tell me was correct by watching the enamel flow down and gloss over in the furnace. This firing was done by radiation, having the gas cut off entirely, and the atmosphere was oxidizing. (*b*) Reducing. This firing was done with excess gas flowing into the furnace, producing a reducing atmosphere. The piece was removed when finished. (*c*) Overfired. This firing was done at 1700 degrees F and the firing period lengthened by 100% over the time required to just correctly finish the test piece. A piece finishing correctly in four minutes was fired for eight minutes. (*d*) Underfired. This firing was done at 1700 degrees, but the pieces were removed before completely glossed out.

Two white enamels are given in Table II, as well as a brown-black enamel, this completing the series.

TABLE II

WHITE COVER COAT ENAMELS AND A BROWN-BLACK "D1"

	Raw Batch Weights		
	C1	C2	D1
Enamel	...	...	...
Silica	200	200	200
Feldspar	400	400	400
Soda	300	300	300
Borax	70	70	70
Tin Oxide	20	...	...
Cryolite	...	75	...
Black Iron Oxide	...	...	70
Manganese Oxide	...	...	20
a. Correct Fire	Good	Fishscaled	Good
b. Reducing Atmosphere	Shivered	Shivered	Fishscaled
c. Overfired	Good	Fair	Good
d. Underfired	Good Dull	Fair	Good

The most noticeable defects are noted in Tables I and II, but of most interest are the pictures of the cross-section of each enamel resulting from

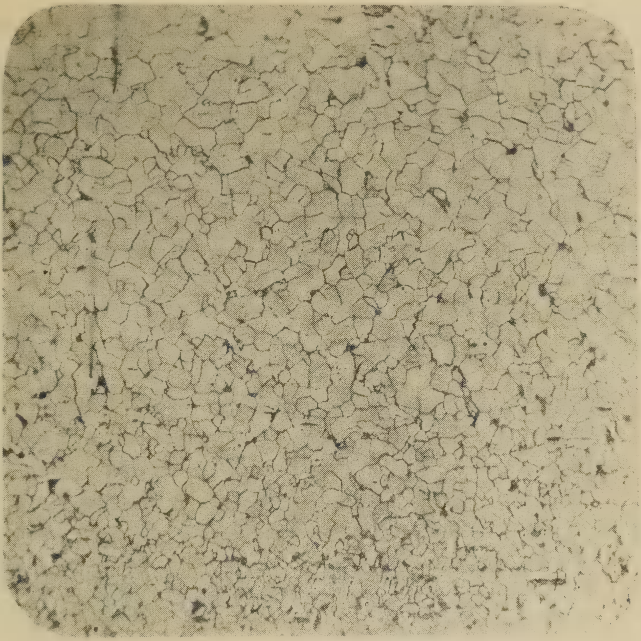

FIG. 1.

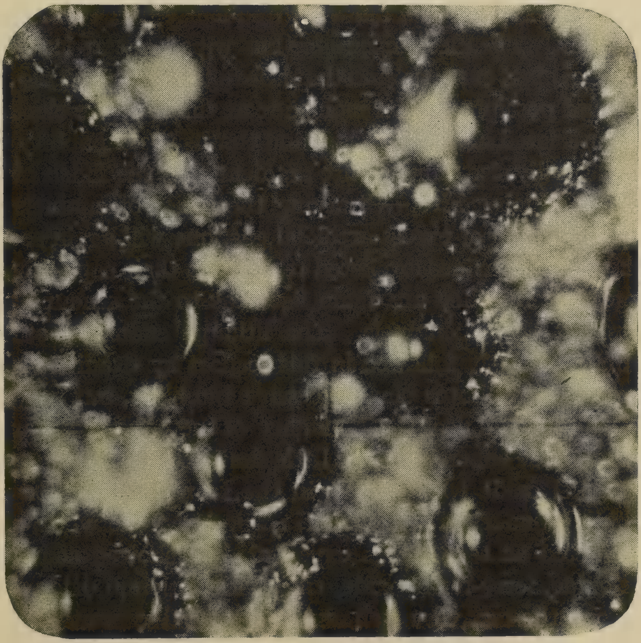

FIG. 2.

the four different types of firing. Glancing over the whole series of ninety-two microphotos, it will be noted that with very slight bubbling indications, either near the steel side or near the intersection of the first and second coat, the ground coat "A" seemed to withstand the successive firings, or in other words had a good firing range. This factor is very important in the industry of heavy plate enameling, where it is not unusual to have a tank in the furnace 40 minutes or longer, while three to four tons of steel are coming to 1700 degrees F or higher. The ground coat used in this series was one the result of which, if fired at a moderate heat beyond its range, was an enamel which would fishscale, while if fired at a higher temperature and beyond its range, it would shiver, leaving a cratered and bubbled undersurface chip as shown in Fig. 2.

In the first series of twenty enamels, the microphotographs of the correct fire all show very little heterogeneous or unmelted matrix as evident in the underfired specimens and just enough of the usual fine bubbling to make a good enamel, with the exceptions of the cryolite cover and titanium oxide cover. There is a well-defined boundary between ground coat and cover coat. An example of a correctly smelted and fired enamel is shown in Fig. 3.

If it were always possible to fire steel ware, so that no portion would receive either a too long or too short time interval, a too high or too low temperature, or a gaseous atmosphere, the need of studying enamel reactions would not attract one; but very frequently one, two or all of these conditions occur. The electric furnace has wiped out at least one of the worst enemies of glass enamels, and that is furnace gas, which may mean sulphur oxides and possibly carbon monoxide at times. The electric furnace should be appreciated in another way, and that is the capability of keeping a correct and goodly size temperature gradient near the finish of the firing.

Results of Reducing Fire.—Studying the series of enamels subjected to the reducing action of excess artificial gas, one will again see that very much as the metallic oxides are listed relative to their capability of giving up an oxygen valent, they are again listed as to the amount and size of bubbles forming in the enamels. The litharge enamels both show excessive bubbling, closely followed in this respect by titanium oxide. The titanium oxide microphotos show excessive bubbling, but very peculiarly it seemed to be located near the boundary of the cover coat and ground. The zirconium oxide enamels show a little similarity to titanium, but not as marked. Nickel oxide when added in the maximum quantity gave excessive bubbling under this treatment. The tin oxide white cover coats were not affected as severely as expected, but showed some reduction. Manganese oxide, ferro-ferric oxide, zinc oxide, calcium oxide and barium oxide withstood the test very well, and their relative position denotes the rating given them, placing manganese first.

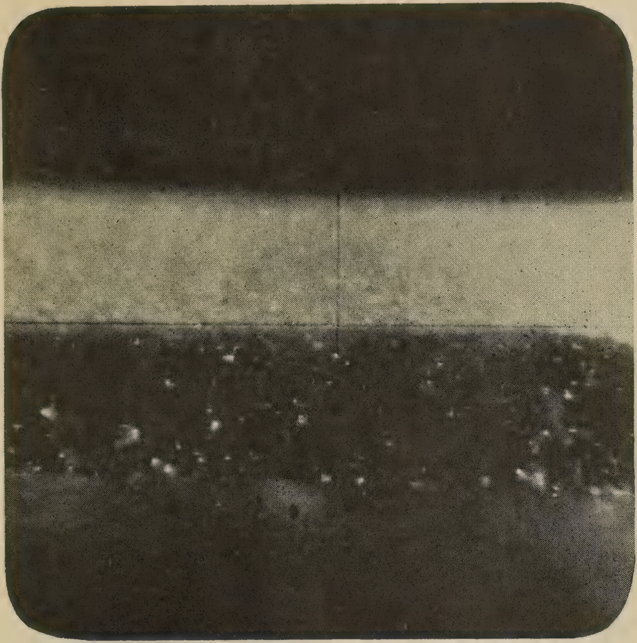

FIG. 3.

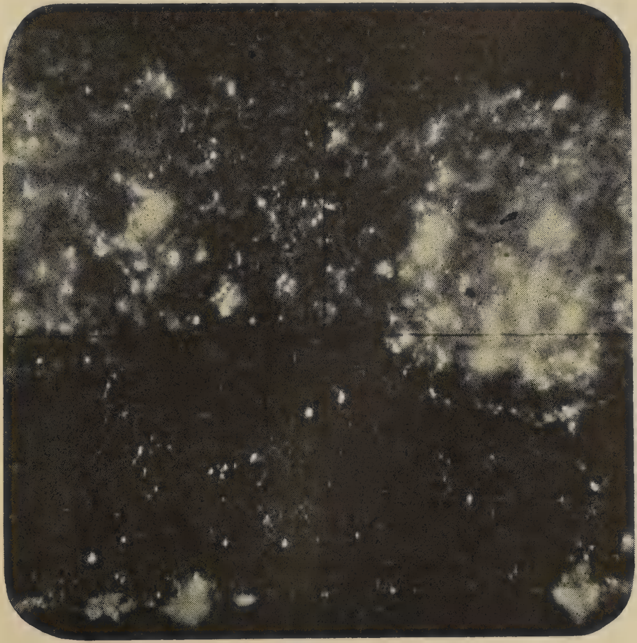

FIG. 4.

Figures 4, 5 and 6 represent examples of excess bubbling under reducing atmosphere.

Figures 7 and 8 show enamels which did not easily yield to this test.

Results of Overfiring.—In the attempt to give the soft enamels a fair test the 100% extra fire system was used. The physical results of this test will be discussed later, but it is well to mention here that by referring to the tabulated chart, one will see that very few enamels survived the test. The enamel B10 plus, the maximum variable content being iron oxide, seemed to withstand the test far better than the others, the firing range being very long. The manganese oxide enamel B1 plus was very good, while enamels B4 minus, B5 minus and B6 minus, containing a minimum variable of barium, calcium and litharge, respectively, were better than the average. The enamels, however, with maximum quantities of these same oxides all shivered or fishscaled to a marked degree. The overfired sample with a minimum quantity of cryolite fishscaled and the photos in Figs. 9 and 10 are interesting in that the reasons are apparent.

Figure 11 shows a titanium enamel not listed in the series which appeared very good from the upper surface, but was likely to shiver at the least strain cause.

The cratered and bubbled condition, which did not subside to a hard glass of dense structure in the case of enamel B2 minus, made it an enamel which when expansion came to play, the edges of the craters no longer offered enough resistance and a shiver resulted. This condition or reaction is most invariably found under a true shiver or large chip, except when caused by a very sharp convex turn in the steel piece. B2 plus or the maximum quantity cryolite enamel, on the other hand, was of such a viscosity and structure at the temperature of 1700 degrees F, lacking metallic oxides to give slight bubbling, so it densely flowed down to a solid glass enamel, melting right in with the ground coat enamel. A strain setting up in this enamel will break, not along crater or bubble boundaries of which there are none, but rather right up through the glass and a fishscale results. The condition of fishscaling and shivering has been quite generally explained by the expansion theory but it rather puzzles one to see apparently the same steel and enamel act differently. Why will the same enamel characteristically fishscale and at other times shiver, while at other times be very good? When we mention shivering, do not mistake it to include a scaling or shivering off due to dirty steel, oxide and slag occlusions or high carbon, but rather the cases which are not answered by these explanations. After examining enamels under the microscope, which included many which had fishscaled, shivered and many which were good, light on a new explanation was seen.

(*a*). An enamel which was heterogeneous in its construction, showing some unmelted matrix, did not fishscale or shiver. This enamel generally

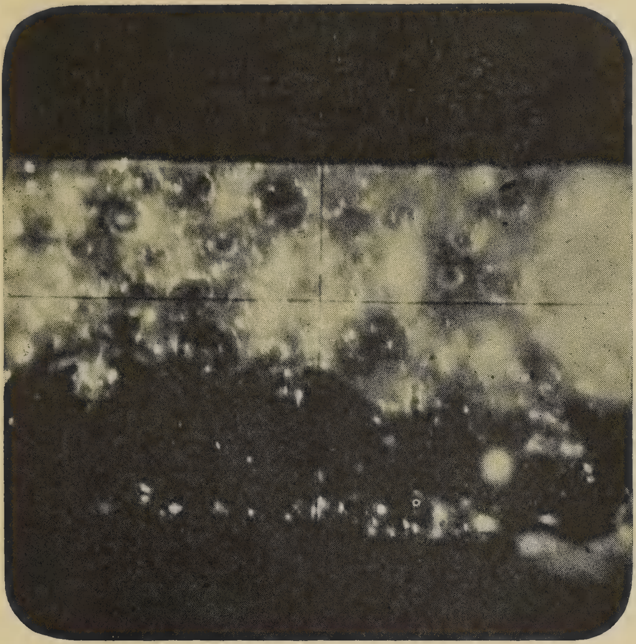

FIG. 5.

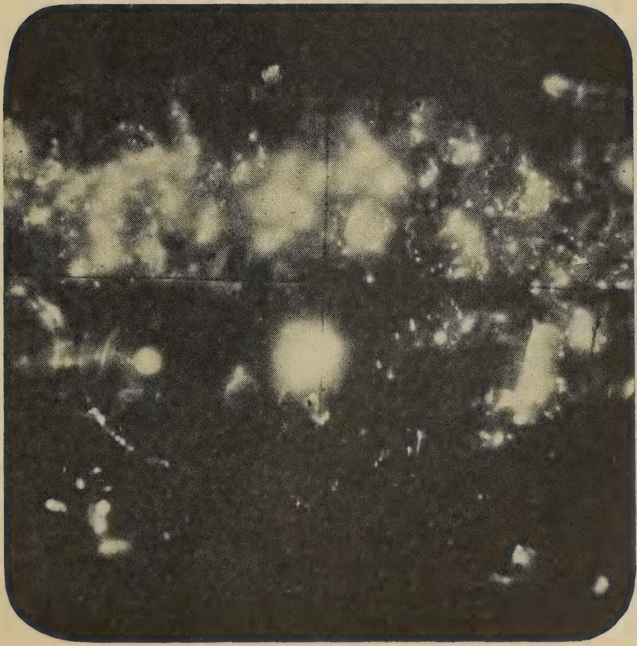

FIG. 6.

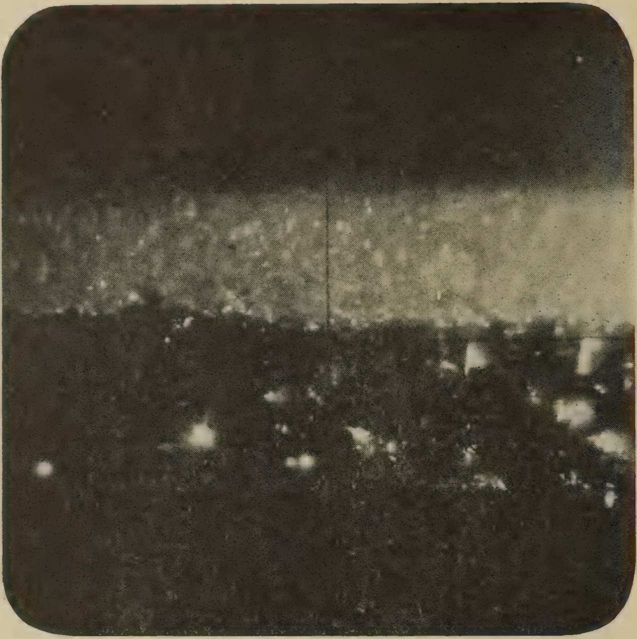

FIG. 7.

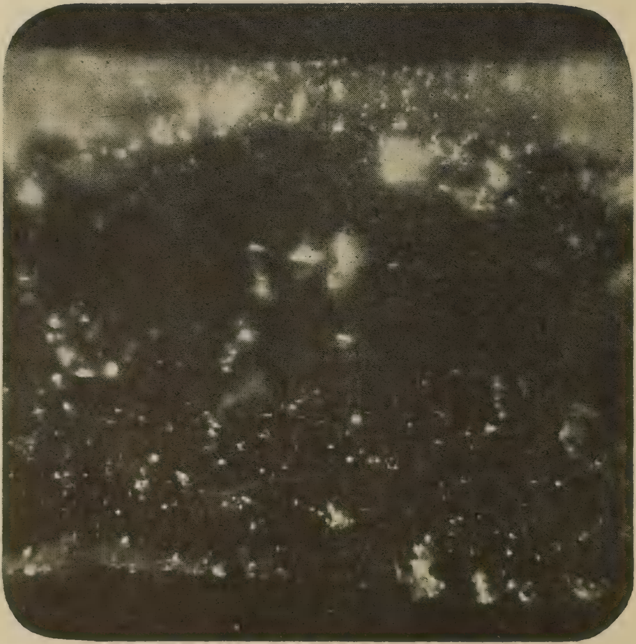

FIG. 8.

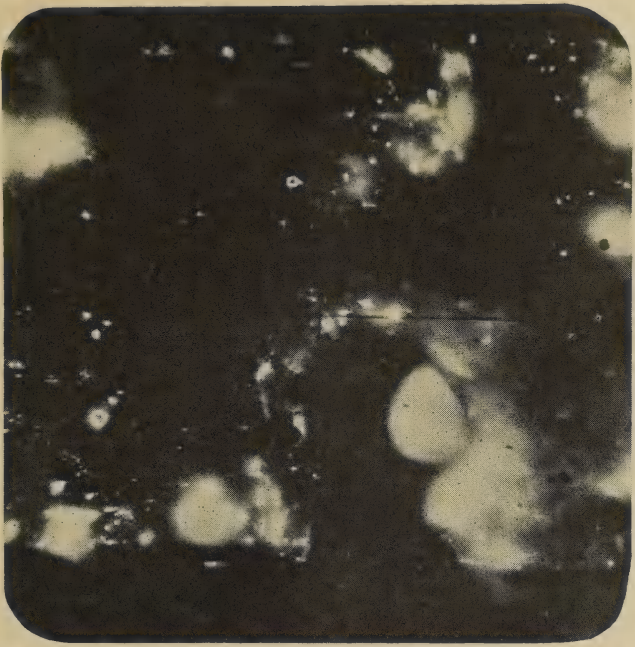

FIG. 9.

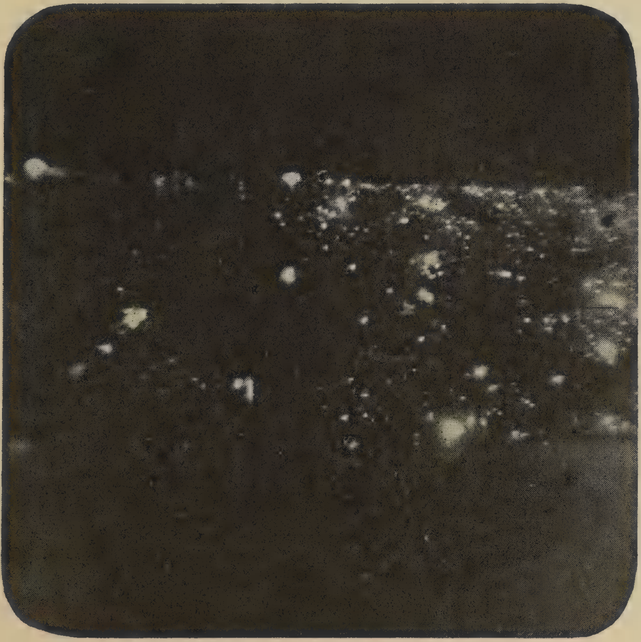

FIG. 10.

was underfired and had quite often other defects, like a dull surface, or was slightly pitted. We must conclude then that the matrix helped or eased up the expansion, even perhaps somewhat increasing the total expansion when needed to meet the steel through certain temperature changing periods, resulting in the enamel not leaving the steel.

(*b*). An enamel which showed a zone or whole cross-section of a dense, clear true glass quite generally fishscaled.

(*c*). An enamel which was excessively bubbled either in a parallel zone to the steel or in a whole cross-section would often shiver.

(*d*). An enamel which showed small uniform bubbling, not being large enough to weaken the structure, was generally free from shivering or fishscaling.

In studying Messrs. Danielson and Souder's expansion tables as well as Mayers and Hava's, it is seen that the more usable and durable enamels are a fair per cent different or rather lower in expansion than steel. Is it not reasonable to conclude that all glass enamels at best are placed under strain by change of temperature, and even at a constant temperature a strain remains?

The strength of the enamel is a main issue, as brought forward by Messrs. Danielson and Souder, and this is a logical conclusion to draw, but also let us reason and add that the resistance without fracture to this strain depends upon the physical structure and partly melted matrix. In other words, a bubbled structure is a helping hand to allow a greater give and take in the enamel until it increases to the point where the air spaces are almost, or are in excess to the true solid glass walls, and then the enamel shivers. It seems reasonable that such a structure could more easily take a lineal or cubical expansion in excess of its mean expansion, if called upon to do so. Following this thought, then, to guard against or to correct a case of fishscaling try to smelt, grind and fire to get an enamel not only of good strength and expansion, which is originally determined by the formula, but also one which has a little partly melted matrix or fine bubbles, or both, giving to the naked eye an enamel which appears glossy and dense. A guide would be to smelt so as not to get a too solid and true glass frit, regulating your batch size, time and smelting temperature preferably as low as possible. Do not mistake this to mean that the temperature of the smelter should be low before charging, for this preferably should be high thereby cutting down the time element, which is important. If possible, add a metallic oxide such as manganese, cobalt, a very little nickel or possibly iron oxide, to accelerate this bubbling when fired on the ware, which explains in part the beneficial effect found true of ground coats with a little metallic oxide addition.[1] When firing the ware, do so at as large

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[1] R. D. Landrum, *Trans. Am. Ceram. Soc.*, **14**, 756 (1912); R. R. Danielson, *Ibid.*, **18**, 343 (1916).

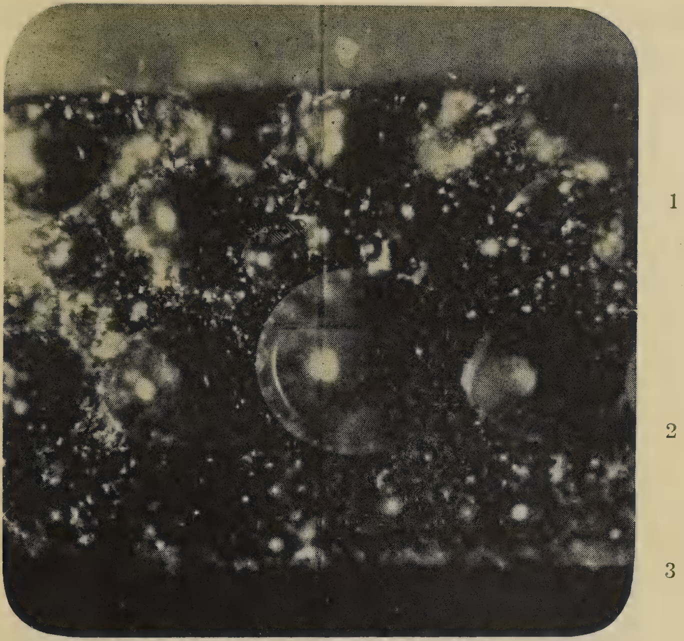

FIG. 11.

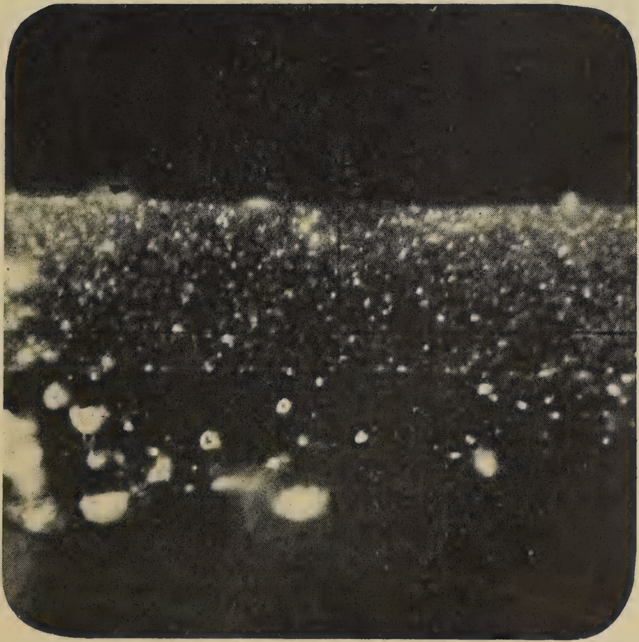

FIG. 12.

a temperature gradient as the shape and construction will allow. More skill is needed in firing this way, but the results are worth it, for the rapid fire will give the structure as mentioned above and also a good enamel in every other respect. The shorter and higher temperature firing just starts unfinished smelter bubbling or mill addition reaction, and also entraps air as very small bubbles, all of which tends to give a correct physical structure. A low heat and long firing period are conducive to fishscaling, for this is an ideal condition under which the enamel will flow down and the bubbles fine out completely or nearly so. Especially is this true if the enamel is low in viscosity and low melting. Lastly a raw mill addition will tend to this structure under firing periods which are not unreasonably long or temperatures which are not too high. Most enamelers have well experienced the good effects of a raw mill addition to an enamel to remedy fishscaling, this addition generally being other than clay.

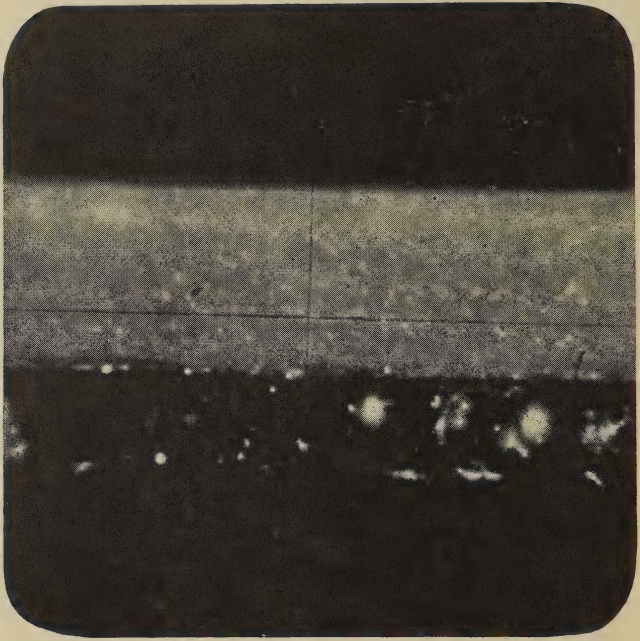

FIG. 13.

Underfiring.—The series of microphotos showing the different enamels underfired are interesting because of one fact and that is their close resemblance and structure relation to a correct fired specimen. In most instances the partly melted matrix is easily picked up under the microscope. It was rather difficult to determine the comparative period at which time the pieces were correctly termed underfired. The following are examples of underfired enamels taken from the series. See Figs. 12 and 13.

Conclusions

(*a*). The degree of susceptibility of enamels to furnace gases is easily classified by cross-section examination under the microscope.

(*b*). The excess intermingling of ground coat and cover coat, meaning that their flowing temperatures are too close to one another, as well as possible interaction between ingredients can be determined. The lack of firing range of either ground or cover coat can quickly be noted.

(*c*). The tendency of a continued excess gasifying of the enamel on the ware especially at high temperatures will be seen, as in the case of enamels containing high titanium oxide.

(*d*). The high viscosity of enamels which do not allow the ready escape of occluded air and gases, thereby forming large bubbles and a resulting weak structure, can be studied. The very opposite of this condition, causing very dense glass-like structure, can be studied.

(*e*). And, finally, the relation of all these factors in helping to explain characteristic fishscaling and shivering, which were summarized under the heading "Overfired."

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A MODIFICATION OF THE EMPIRICAL FORMULA IN GLAZE AND ENAMEL CALCULATIONS[1]

By J. E. Hansen[2]

ABSTRACT

Objections to the Usual Type of Molecular Formula.—The shortcomings, disadvantages and objections to the usual type of molecular formula are reviewed, and it is shown by calculation back to the batch mixture how the molecular formula may be misinterpreted.

New Type of Molecular Formula Proposed.—The following type of an empirical formula is proposed.

$$\left.\begin{array}{ll} \mathrm{Na_2O} & \ldots\ldots \\ \mathrm{Na_2F_2} & \ldots\ldots \\ \mathrm{K_2O} & \ldots\ldots \\ \mathrm{CaO} & \ldots\ldots \\ \mathrm{CaF_2} & \ldots\ldots \\ \mathrm{BaO} & \ldots\ldots \\ \mathrm{ZnO} & \ldots\ldots \\ \mathrm{PbO} & \ldots\ldots \end{array}\right\} \begin{array}{ll} \mathrm{Al_2O_3} & \ldots\ldots \\ \mathrm{Al_2F_6} & \ldots\ldots \end{array} \left\{\begin{array}{ll} \mathrm{SiO_2} & \ldots\ldots \\ \mathrm{SiF_4} & \ldots\ldots \\ \mathrm{B_2O_3} & \ldots\ldots \\ \mathrm{Sb_2O_3} & \ldots\ldots \end{array}\right.$$

Advantages of New Type.—The advantages of this new type of formula are that (1) it presents its data in the usual simple and graphic manner; (2) it indicates the mineralogical and physical condition in which most of the important constituents are introduced into the batch; (3) it admits of but little danger of obtaining the wrong batch mixture upon calculation back to the raw materials; and (4) the conclusions to be drawn from it are quite fixed and definite.

The graphic empirical formula has long been, and still continues to be, one of the methods of expressing glaze and enamel composition, as well as other ceramic mixtures. The empirical formula is an aid to the ceramist in that it is a means to the simple and graphic expression of the oxides present in a ceramic composition, but, unfortunately, there are disadvantages and objections to the use of this method.

It is not the intention of this paper to defend or advocate the use of the empirical formula as it is now considered, but again to call attention to its disadvantages and suggest a form which will relieve the situation.

Concerning the use of empirical formulas, Seger says,[3] "*the formulas merely express that the elements indicated are present in certain proportions*, and it does this in a simple and graphic manner, from facts which can only be deduced from an analysis of the material."

Edward Orton, Jr.,[4] referring to empirical formulas, states that "these methods are merely mechanical aids to expression, and are not in themselves a correct statement of chemical fact."

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[1] Read before Enamels Division, St. Louis Meeting, Feb. 28, 1922.

[2] Industrial Fellow, Mellon Institute of Industrial Research of the University of Pittsburgh, Pittsburgh, Pa.

[3] "Collected Writings of Seger," **2,** 562 (1902).

[4] *Trans. Am. Ceram. Soc.,* **3,** 80 (1901).

Homer F. Staley[1] says, "it is a decided disadvantage that the formulae are based on a recalculation of the gross analysis of the material, *thus neglecting the mineralogical and physical condition in which the various elements are introduced.* These neglected factors may be vastly more important when comparing two mixes than the formal similarity of ultimate analysis. If, to obviate this limitation, we try to work with empirical formulae, and at the same time keep in mind our batch, our problem becomes as complex as working with batch weights, thus annulling its one great advantage, *i. e.*, its graphic character."

Ross C. Purdy[2] says, "The alkalies introduced into glazes as a constituent part of a frit have very different influence according to the difference in their source."

Another objection lies in the placing of fluorine as F_2 in the acid group, for the fluorine is not introduced, present, or liberated as free F_2. Hence, calling it F_2 leads to a misconception of chemical fact. Further, it is the usual custom, in comparing two mixes, to consider the fluorides as minerals and not as mixtures of the oxides,[3] to which we arbitrarily calculate them in the usual molecular formula.

Therefore, it is proposed that, instead of using the regular form of empirical formula, a modified or enlarged form be used, in which, for the main part, instead of calculating the various fluorides over to the corresponding oxides (as is done in the regular molecular formula), they be incorporated into the formula as the fluoride and placed in their regular place in the formula, according to whether their oxide is basic, amphoteric, or acidic in character.

For example, take an enamel, which, according to the usual method of expressing the molecular formula, has the following composition:

$$\left.\begin{array}{l} 0.357\ \mathrm{Na_2O} \\ \ \ .083\ \mathrm{K_2O} \\ \ \ .172\ \mathrm{CaO} \\ \ \ .080\ \mathrm{BaO} \\ \ \ .242\ \mathrm{ZnO} \\ \ \ .066\ \mathrm{PbO} \\ \hline 1.000 \end{array}\right\} \quad 0.120\ \mathrm{Al_2O_3} \quad \left\{\begin{array}{l} 1.016\ \mathrm{SiO_2} \\ \ \ .244\ \mathrm{B_2O_3} \\ \ \ .044\ \mathrm{Sb_2O_3} \\ \ \ .323\ \mathrm{F_2} \end{array}\right.$$

In calculating the above empirical formula back to the batch formula, it would be usual to make the assumption that all B_2O_3 is to be derived from borax if it is possible to do so without adding too much Na_2O, that as much K_2O shall be derived from feldspar as is possible without introducing too much Al_2O_3, that all F_2 comes from fluorspar and cryolite, all CaO from fluorspar, all BaO from $BaCO_3$, ZnO from zinc oxide, PbO from litharge,

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[1] *Trans. Am. Ceram. Soc.*, **13,** 123 (1911).

[2] *Ibid.*, **13,** 195 (1911).

[3] *Ibid.*, **13,** 502 (1911).

TABLE I

CALCULATION OF MOLECULAR FORMULA TO BATCH FORMULA

Formula											Material used	Molecular parts	Formula weight	Batch weight	Batch for 1000 melted
Na_2O	K_2O	CaO	BaO	ZnO	PbO	Al_2O_3	SiO_2	B_2O_3	Sb_2O_3	F_2					
.357	.083	.172	.080	.242	.066	.120	1.016	.244	.044	.323					
..	..	.172	..	..	..	..	...	..	..	.172	Fluorspar	.172	× 78	13.42	68.5
										.151	CaF_2				
.075	..	..	..	..	..	.025	...	..	..	.151	Cryolite	$\frac{.151}{6}$	× 420	10.58	54.0
.282						.095					$6NaF.Al_2F_6$				
.055	.032	..	..	..	..	.095	.732	..	..	..	Feldspar	$\frac{.095}{1.1}$	× 695	60.10	307.0
.227	.051						.284				.367 K_2O				
											633 Na_2O } 1.1 Al_2O_3 {8.45 SiO_2				
..	..	..	..	..	..	..	.284	..	..	..	Quartz	.284	× 60	17.04	87.0
											SiO_2				
.122	..	..	..	..	..	..	...	.244	..	..	Borax	$\frac{.244}{2}$	× 382	46.60	238.0
.105											$Na_2O.2B_2O_3.10H_2O$				
..	.051	..	..	..	..	..	...	..	..	..	Potassium Nitrate	.051	× 202	10.30	52.5
.105											KNO_3				
..	..	..	..	..	..	..	...	..	..	..	Soda Ash	.105	× 106	11.13	56.8
											Na_2CO_3				
..	..	..	.080	..	..	..	...	..	..	..	Barium Carbonate	.080	× 197	15.75	80.2
											$BaCO_3$				
..	..	..	..	.242	..	..	...	..	..	..	Zinc Oxide	.242	× 81	19.60	100.0
											ZnO				
..	..	..	..	..	.066	..	...	..	..	..	Litharge	.066	× 223	14.72	75.0
											PbO				
..	..	..	..	..	..	..	...	..	.044	..	Antimony Oxide	.044	× 288	12.66	64.5
											Sb_2O_3				
														232.50 equals 196.0 melted	1183.5 equals 1000 melted

and Sb_2O_3 from antimony oxide, using flint and clay, if necessary, to fulfill the requirements for Al_2O_3 and SiO_2. However, in studying this formula, it is found that all the K_2O could not come from feldspar because there is not enough Al_2O_3; neither can it be assumed that all the Al_2O_3 comes from feldspar and the balance of the K_2O from pearl ash or saltpetre, because then the F_2 can not be balanced up by the usual assumption that it comes from fluorspar and cryolite.

Hence, it is necessary to start our calculations with fluorspar, supply the remaining F_2 from cryolite, and take the balance of the Al_2O_3 as the index of the feldspar used.

The calculations of this empirical formula back to the batch mixture, using a feldspar of the composition

$$\begin{array}{lll} 0.367\ K_2O & 1.100\ Al_2O_3 & (8.47\ SiO_2) \\ \underline{.633\ Na_2O} & & \\ 1.000 & & \end{array}$$

with a molecular weight of 695, are shown in Table I.

However, upon comparing this batch formula with the *original* batch formula from which this empirical formula was derived, it is found that the fluorspar, cryolite, quartz and soda ash are materially higher than they should be, that feldspar is lower, and that two constituents, namely, sodium silicofluoride and whiting, are missing entirely.

Table II

	Original batch# formula for 1000# melted	Batch formula for 1000# melted as calculated from empirical formula
Feldspar	342	307.0
Quartz	50	87.0
Borax	238	238.0
Soda Ash	50	56.8
Potassium Nitrate	50	52.5
Barium Carbonate	80	80.2
Zinc Oxide	100	100.0
Litharge	75	75.0
Whiting	30	...
Fluorspar	45	68.5
Cryolite	30	54.0
Sodium Silicofluoride	40	...
Antimony Oxide	64	64.5

The theoretical melted percentage composition, as shown on the following page, also differs from the composition of the original batch.

This variation in the batch formula is due to the fact that the empirical formula neglects the mineralogical and physical condition in which the various elements are introduced, and, hence, can not be correctly inter-

TABLE III

THEORETICAL MELTED PERCENTAGE COMPOSITION

	Original batch	As calculated from empirical formula
Silica	29.80	31.03
Silicon Fluoride	2.22	...
Alumina	5.51	4.95
Aluminum Fluoride	1.20	2.16
Boric Oxide	8.71	8.71
Sodium Oxide	8.66	8.87
Sodium Fluoride	3.58	3.24
Potassium Oxide	4.02	3.97
Calcium Oxide	1.68	...
Calcium Fluoride	4.50	6.85
Barium Oxide	6.22	6.23
Zinc Oxide	10.00	10.00
Lead Oxide	7.50	7.50
Antimony Oxide	6.40	6.45
	100.00	99.96

preted. That this variation would lead to an enamel of vastly different physical properties than the original enamel is, no doubt, undisputed.

However, if the empirical formula is expressed as below

$$\left.\begin{array}{l} 0.274\ Na_2O \\ .083\ Na_2F_2 \\ .083\ K_2O \\ .059\ CaO \\ .113\ CaF_2 \\ .080\ BaO \\ .242\ ZnO \\ .066\ PbO \\ \hline 1.000 \end{array}\right\} \quad \begin{array}{l} 0.106\ Al_2O_3 \\ .014\ Al_2F_6 \end{array} \quad \left\{\begin{array}{l} 0.974\ SiO_2 \\ .042\ SiF_4 \\ .244\ B_2O_3 \\ .044\ Sb_2O_3 \end{array}\right.$$

it will be seen at a glance in exactly what mineralogical and physical condition most of the constituents are introduced. The simple graphic form of the expression is still retained, and it is no longer necessary to keep in mind the batch formula when comparing two mixes as to their physical properties.

An examination of this modified form of expression shows the ingredients of the enamel, as evidenced by the following "mental analysis:"

1. Since this is evidently a cover enamel and the use of clay or aluminum oxide unlikely, the amount of soda-potash feldspar in the enamel is indicated by the content of Al_2O_3. In cases where it is evident that K_2O was not introduced in any other form, it could also be taken as an index of the amount of feldspar.

2. The K_2O in the feldspar used is approximately one-third that of

TABLE IV

CALCULATION OF MOLECULAR FORMULA TO BATCH FORMULA

Formula														Material used	Molecular Parts	Formula weight	Batch weight	Batch for 1000 melted
Na_2O	Na_2F_2	K_2O	CaO	CaF_2	BaO	ZnO	PbO	Al_2O_3	Al_2F_6	SiO_2	SiF_4	B_2O_3	Sb_2O_3					
.274	.083	.083	.059	.113	.080	.242	.066	.106	.014	.974	.042	.244	.044					
..	..	..	..	.113	..	..	..	..	..	..	..	..	..	Fluorspar	.113	× 78	8.81	45.0
														CaF_2				
..	.042	..	..	..	..	..	..	..	.014	..	..	..	..	Cryolite	.019	× 420	5.88	30.0
	.041													$6NaF.Al_2F_6$				
.061	..	.035	..	..	..	..	..	.106	..	.813	..	..	..	Feldspar	$\frac{.106}{1.1}$	× 695	67.00	342.0
.213		.048								.161				$.367K_2O$ } $1.1Al_2O_3$ {8.45				
														$.633Na_2O$ } SiO_2				
..	..	..	..	..	..	..	..	..	..	.161	..	..	..	Quartz	.161	× 60	9.66	49.3
														SiO_2				
.122	..	..	..	..	..	..	..	..	..	..	..	.244	..	Borax	$\frac{.244}{2}$	× 382	46.60	238.0
.091														$Na_2,O.2B_2O_3.10H_2O$				
..	..	.048	..	..	..	..	..	..	..	..	..	..	..	Potassium Nitrate	.048	× 202	9.70	49.5
														KNO_3				
.091	..	..	..	..	..	..	..	..	..	..	..	..	..	Soda Ash	.091	× 106	9.65	49.3
														Na_2CO_3				
..	..	..	..	..	.080	..	..	..	..	..	..	..	..	Barium Carbonate	.080	× 197	15.75	80.2
														$BaCO_3$				
..	..	..	..	..	..	.242	..	..	..	..	..	..	..	Zinc Oxide	.292	× 81	19.60	100.0
														ZnO				
..	..	..	..	..	..	..	.066	..	..	..	..	..	..	Litharge	.066	× 223	14.72	75.0
														PbO				
..	..	..	..	..	..	..	..	..	..	..	..	..	.044	Antimony Oxide	.044	× 288	12.67	64.5
														Sb_2O_3				
..	..	..	.059	..	..	..	..	..	..	..	..	..	..	Whiting	.059	× 100	5.90	30.0
														$CaCO_3$				
..	.041	..	..	..	..	..	..	..	..	..	.042	..	..	Sodium Silicofluoride	.0415	× 189	7.84	40.0
														Na_2SiF_6				

Al_2O_3. Hence, that K_2O was introduced into this enamel, no doubt as either the carbonate or the nitrate, is evidenced by the fact that K_2O in the empirical formula is greater than one-third the value for Al_2O_3.

3. That flint or quartz also was used is evidenced by the fact that the SiO_2 in the empirical formula is greater than $.106 \times 7.7$, which is the amount of silica in the feldspar.

4. That cryolite was used is evidenced by the fact that .014 equivalents of Al_2F_6 are included in the formula. This also accounts for .042 equivalents of Na_2F_2.

5. That sodium silicofluoride was used is shown by the corresponding equivalents of unaccounted for Na_2F_2 and of SiF_4.

6. Borax, antimony oxide, calcium carbonate, fluorspar, barium carbonate, zinc oxide and litharge are used, as is evidenced by the B_2O_3, Sb_2O_3, CaO, CaF_2, BaO, ZnO and PbO in the expression.

7. Soda ash or sodium nitrate must be used to supply the remaining Na_2O needed.

That this modification of the empirical formula can be calculated back to the batch formula without so much danger of obtaining the wrong batch mixture can be seen by comparing the batch mixture as calculated below with the original batch mixture.

This scheme of arrangement violates no stoichiometrical relations and is in no way contradictory of the old type of empirical formula, but merely enlarges upon it. Further enlargement can be made if desired, such as separating the alkalies introduced with the feldspar from those introduced as soluble salts. Barium fluoride would be treated like fluorspar and entered as BaF_2. If B_2O_3 be introduced as boric acid, this would no doubt be evident from the intermolecular relationship of B_2O_3 and Na_2O in the empirical formula, but if desired B_2O_3 as introduced from boric acid could be designated as $B_2O_3.3H_2O$, as in the glaze formula below:

$$\left.\begin{array}{l} .10\ K_2O \\ .20\ Na_2O \\ .40\ CaO \\ .30\ PbO \end{array}\right\} \qquad .40\ Al_2O_3 \qquad \left\{\begin{array}{l} 3.15\ SiO_2 \\ .40\ B_2O_3 \\ .10\ B_2O_3(3H_2O) \end{array}\right.$$

Hydrated oxide of aluminum could also be treated in a similar manner as $Al_2O_3.3H_2O$.

The presence of lepidolite, which is gaining favor as an enamel material, would probably be indicated by the presence of Li_2O in the empirical formula, for it is unlikely in the ordinary enamel that Li_2O would be introduced as the more expensive carbonate. In calculating an enamel containing lepidolite back to the batch formula it would be necessary to figure the lepidolite before attacking the feldspar and alkalies.

If ZrO_2 appears in the empirical formula, the intermolecular proportions of ZrO_2 and SiO_2 (considered with the feldspar) may indicate whether the

ZrO_2 was introduced as the oxide or silicate. In case there is no such easily apparent relationship, one might have to make an arbitrary choice.

This modification does not clearly establish the source of Na_2O as to whether it is introduced as the nitrate or carbonate, and it is not within the scope of this paper to discuss what difference their interchange would make in the physical properties of an enamel, but it is believed that this form of expression possesses sufficient other redeeming qualities to warrant its use. Neither is it claimed that this modification of the empirical formula is a correct statement of chemical fact as regards the state of combination of the various constituents of the fritted mass, for the equilibrium relations attained will depend on the temperature and length of time of smelting, but the author knows of no expression which can state this relation.

The advantages of this modification of the empirical formula are as follows:

1. It presents its data in the usual simple and graphic manner;
2. It indicates the mineralogical and physical conditions in which most of the important constituents are introduced into the batch;
3. It admits of but little danger of obtaining the wrong batch mixture upon calculation back to the raw material; and
4. The conclusions to be drawn from it are quite fixed and definite.

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THE PLASTICITY OF CLAYS[1]

By F. P. Hall[2]

ABSTRACT

Discussion of the term "plasticity" and the methods brought forward for the measurement of plasticity; the factors which each measures; the use of the Bingham plastometer as an instrument for determining relative plasticity of clays; the need for more efficient methods of measuring plasticity.

Introduction

The idea of plasticity as held by ceramists may be defined as the property which enables a body, soft enough to be moulded without cracking, to retain its shape permanently after it has been subjected to a deforming pressure. The bonding power of the dried clay is another distinct property and should not be implied when speaking of plasticity. The plasticity of clays has been attributed to the presence of matter in a colloidal state. It is known that the size of the grains of a substance markedly affects the plasticity of the substance. It has been shown that extremely fine-grained clays and extremely coarse-grained clays are less plastic than clays composed of both fine and coarse grains mixed. It is highly probable that the distribution of grain-sizes which permits the closest packing of particles will be most favorable to high plasticity. The compact mass resulting from the close packing of particles will evidently offer the greatest resistance to being deformed. Clays exhibit many properties common to substances in the colloidal state such as: hydrolysis, absorption, shrinkage, ability to change from gel to sol form and *vice versa*. This analogy between clays and substances in the colloidal state has led investigators to look to the field of colloidal chemistry for a possible solution of the problem of plasticity.

From the above discussion of plasticity we see that there are two factors to be considered in measuring this property, namely: (1) resistance which a clay offers to changing its shape; (2) the amount of deformation which a clay can suffer without cracking. Mellor[3] suggests that the following formula is the mathematical definition of the term plasticity:

$$\text{Plasticity} = \frac{\text{Cohesion}}{\text{Internal friction}}$$

Cohesion can be represented as the amount of deformation that a clay can suffer without cracking and internal friction as the resistance that a clay offers to changing its form.

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[1] Published by permission of the Director, U. S. Bureau of Standards.

[2] Received April 10, 1922.

[3] "On the Plasticity of Clays," by J. W. Mellor, Communication from the Clay and Pottery Laboratory, Stoke-on-Trent No. 53.

Methods of Measuring Plasticity

Numerous methods have been brought forward for measuring this important property of clays but few can be recommended due to the fact that the methods are empirical and do not measure plasticity but some property closely allied to it. Many methods proposed for measuring plasticity are based on the bonding power of the dried clay. This bonding power of the dried clay is a distinct property of the clay and should not be confused with the plasticity. We will not consider these methods in this article.

On account of the heterogeneity of the system clay–water it is very difficult to formulate mathematical equations that will satisfy the observations. With most of the methods it is very difficult to obtain concordant results. The apparent wetness or consistency of a clay-water mixture is influenced by several factors, namely, (1) past history of clay, (2) type of clay, (3) amount of working the mixture has received, (4) time of contact of clay and water, (5) temperature of mixture, (6) amount of water. Some of these factors are not easily controlled and hence it is difficult to obtain results that are satisfactory.

The first method to be considered is the dye-absorption test. Ashley assumed that the plasticity of a clay was inversely proportional to the grain size, and hence the clay that had the highest colloidal content was the most plastic. Plasticity is not, however, entirely due to the presence of colloidal matter in clays, though the effects of colloids in increasing plasticity can not be denied. In determining the colloid content Ashley used the dye-absorption test. The absorption of a clay is usually determined by noting the loss of color of a dye solution, such as malachite green, and comparing it with another similar solution to which a standard clay has been added. It is known that different colloids have different absorptive powers towards a single dye and it is not reasonable to assume that the colloidal matter in all clays is the same, hence this method of determining the colloid content is open to a serious objection. In other words, in order for this method to be correct the colloidal matter in different clays would have to have the same absorptive power and this is not the case.

Method of G. E. Stringer and W. Emery

It is known that plasticity varies with the proportion of water mixed with the clay. The possible plasticity is that which can be developed under the best known conditions. The possible plasticity of a clay can not be developed by commercial methods unless the material is in a state which may be regarded as dormant plasticity. Messrs. Stringer and Emery have measured the relations between the proportion of water in the clay and the resistance the clay offers to changing its shape, and the deformation the clay can suffer without cracking. Their method is briefly: A sphere of clay mixture is made 2 cm. in diameter. This sphere is placed upon a glass slab and this placed under a vertical piston. Weights are added to the piston to cause it to descend upon the clay sphere. The descent of the piston is stopped when vertical cracks appear on the edge of the disc. The distance moved by the descending piston is taken to represent the amount of deformation the clay could suffer without cracking; and the weight required to compress the clay sphere a definite distance is taken to represent the resistance the clay offered to changing its shape. They found by this method that as water is progressively added to a clay, the plasticity increases to a maximum and then as more water is added the plasticity gradually decreases. The chief difficulty with this method seems to be in making the clay sphere. Cylindrical test pieces are not as satisfactory as spherical ones. The results are expressed in plasticity units which are empirical. It is difficult to obtain concordant results and the method will have to be modified before it will be satisfactory. It was found that the greater the plasticity of the clay, the greater the proportion of water required to develop the maximum plasticity. A ball clay required 30 per cent of water before becoming sticky, a kaolin required 20 per cent, while a very short clay required only 10 per cent of water to make it sticky.

The MacMichael Torsional Viscosimeter

This instrument was first brought forward to determine the so-called "viscosity" of clay slips. It is at present used to determine the viscosity of liquids. It will be shown later that clay slips are not liquids but plastic substances. The torsional viscosimeter is an instrument for determining the viscosity of a liquid by a torsional balance, usually consisting of two concentric cylinders, one of which has an angular motion about their common axes. One of the cylinders is suspended by a fine wire, thus forming a torsional pendulum. In the MacMichael instrument the outer cylinder rotates at constant speed. The inner cylinder rotates until the torsional force in the suspending wire balances the viscous resistance, and then remains in a fixed position so that a reading may be taken. In the case of viscous liquids if the speed of rotation of the outer cylinder is plotted against the angular deflection of the inner cylinder, the result will be linear and pass through the origin. If a plastic substance is tested the result will be linear at high speeds but the linear portion of the curve extended will not pass through the origin but will intersect the deflection axis at a definite point above the origin. Clay slips behave like plastic substances in this instrument. This instrument has been tested out at the Bureau of Standards with different clay slips. The results are not reproducible, due to what may be called a "puddling effect." Thus as the outer cylinder rotates, that part of the slip immediately surrounding the inner cylinder changes in consistency as the stirring continues. Another difficulty in testing clay slips in this type of instrument is that of filling the outer cup to the proper height. In dealing with a substance that does not flow freely under its own weight it is very difficult to pour the substances into a container so that the entire surface will be at the same level.

This "puddling effect" observed in this type of instrument is likely to be present in any instrument designed for this type of substance as long as the agitation is local and does not extend to the entire mass. In a clay slip the particles are not free to move about, hence we have local agitation within the outer cup immediately surrounding the inner cylinder and this agitation changes the apparent wetness of this part of the slip. This instrument in its present form can not be recommended for the testing of clay slips. The curves obtained by testing clay slips with this instrument are very similar to those obtained with the Bingham instrument which will be described in another portion of the article.

The Emley Plasticimeter

This instrument is described in Bureau of Standards Technologic Paper No. 169 by Mr. Warren E. Emley. Mr. F. A. Kirkpatrick and Mr. W. B. Orange used this instrument for testing clays and limes and made a report of the results in an article in *Journal of the American Ceramic Society.*[1] The results are expressed in a term called the "plasticity figure" which is empirical depending upon the dimensions of the instrument. Mr. Emley states that the consistency has little influence upon the plasticity. This is not consistent with the definition of plasticity as commonly given by the ceramist. The ceramist recognizes the fact that the plasticity is greatly affected by the water content of the clay mixture. There seems to be a difference in the definition of plasticity as given by the ceramist and that given by the plasterer. Hence the plasticimeter is not measuring the same property that is designated as plasticity by the ceramist. The plasticimeter measures the property of retaining water and the resistance to deformation under pressure that a substance possesses. This instrument gives a measure of only one of the two factors of plasticity and an additional factor, namely, the property of retaining water. This instrument seems to have given good results for the use of plasterers and investigators of lime and plaster because in this field the term plasticity does not have the same meaning as in the field of the clay worker. This instrument in its present form can not be recommended to the clay worker as an instrument for determining the property which he calls plasticity.

[1] *Jour. Am. Ceram. Soc.*, **2,** 44 (1919).

Atterberg Plasticity Method[1]

This method is based upon the varying physical behavior of clays with different water contents. The range of water content over the workable stage is determined. The workable stage is bounded by two points which are arbitrarily fixed, one point being that at which the clay mass will barely flow and the other the point at which the clay mass can no longer be rolled into threads. It is Atterberg's contention that the wider this range the more plastic is the clay. The results are expressed in a unit designated as the "plasticity number," which is empirical. This "plasticity number," along with the per cent water of plasticity, is supposed to determine the plasticity of the clay.

It is evident that in a method of this type too much is left to the judgment of the person conducting the tests. For comparative tests this method seems to have met with a fair degree of success.

The Bingham Plastometer[2]

If clay be suspended in water the fluidity is lowered rapidly and in a perfectly linear manner. As the proportion of clay increases a concentration is reached where the fluidity is zero as measured in an ordinary viscosimeter. Thus these instruments are not available for measuring the viscosity of suspensions above that critical concentration where the substance ceases to act as a viscous liquid. Prof. E. C. Bingham has developed an instrument for the investigation of substances of plastic nature. In using this instrument the rate of flow through a capillary tube under a definite constant pressure head is determined. The flow at several pressures having been determined, the volume discharged per second is plotted against the pressure producing the flow. For true viscous liquids the relation is linear and passes through the origin; for plastic substances the relation is linear at high pressures but if this linear portion of the curve is extended to the pressure axis it will not intersect the axis at zero but at a finite point on the pressure axis. Fig. 1 illustrates this difference between the two states of substances. The fact that with plastic substances the linear portion of the curve does not pass through the origin shows that with substances in this state a certain defi-

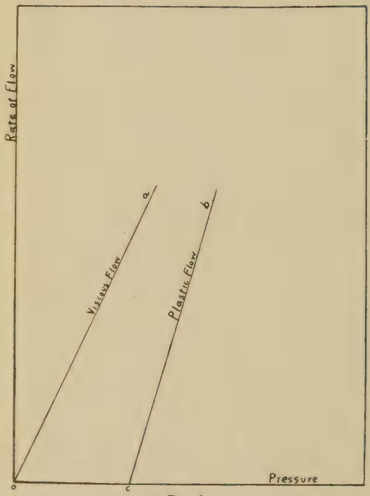

Fig. 1

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[1] Technologic Paper of the Bureau of Standards, No. 46.

[2] Proceedings, *Am. Soc. Test. Mats.*, **19,** II (1919), **20,** II (1920).

nite pressure must be exceeded before the substance will flow. This definite initial friction value that has to be exceeded distinguishes the plastic state from the viscous state. The experiments by Bingham support the definition by Maxwell (Theory of Heat) that a plastic body is one in which the body is found to be permanently altered when the stress exceeds a certain value. The following relation between certain terms is given by Bingham and Green:

Solids (including plastic materials)	Liquids
Rigidity (R) comparable with......	viscosity (η)
Mobility (μ) comparable with......	fluidity (θ)
$\mu = \frac{1}{R}$	$\theta = \frac{1}{\eta}$

By reference to Fig. 1 the terms will be explained. The slope of the line *a* is determined by the fluidity of the liquid, while the slope of line *b* is determined by the mobility of plastic material, and the intercept of the line *b* upon the pressure axis is determined by the initial friction value of the plastic material. This initial friction value is also designated as yield value. Of two clay slips of equal mobility, the one having the higher yield value is the more plastic, while of two clay slips of equal yield value, the one having the higher mobility is the more plastic.

Plastic clay in the form of a cylinder or cube, for example, will maintain its form provided pressure due to weight does not exceed the yield value. Once the yield value is exceeded the material will flow. If the material is very mobile it will flow with ease; if not, a greater pressure will be required to keep the material in motion. These two factors, mobility and yield value, may be said to define roughly the plasticity of a substance. This conception of plasticity seems to be a more rational definition than that commonly given by ceramists.

The action of different clay-water mixtures is shown in Fig. 2. The mobility of clay-water mixtures can be varied by changing the water content. The practice followed in determining relative plasticity by this method is to make up a clay slip of one of the clays and determine the mobility and yield value of this slip, then take a second clay and vary the water content of the second slip until the mobility is the same as the first, using the same capillary as before. The mobility being constant, the plasticity will vary directly as the yield value.

Fig. 2 shows a comparison between an English ball clay and an English china clay. The ratio $\frac{W}{C}$ is the ratio of water to clay in the slip. Both determinations were made using the same capillary and the results are comparable. The slopes of the lines are the same. The English ball clay has a yield value of 395, while the English china clay has a yield value of 50.

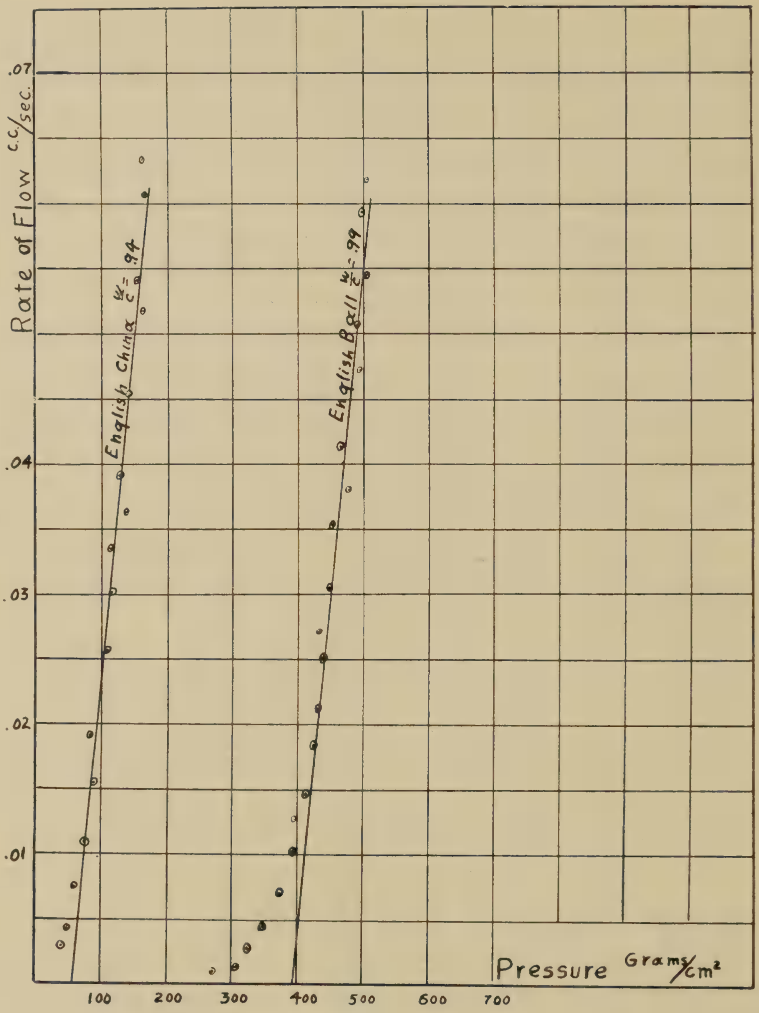

FIG. 2.

No attempt will be made to reduce these results to C. G. S. units. Bingham and Green applied their plastometer method to the investigation of the plasticity of paints and correct mathematical equations for the plastic flow of paints through capillary tubes have been worked out by Dr. E. Buckingham,[1] of the Bureau of Standards. A great deal of work has been done, at the Bureau, on the study of the plastic flow of clays through capillary tubes, and it has been found that the equations for plastic flow of paints do not hold true for clay slips. Hence the results will remain empirical until equations are derived that will satisfy the observations.

[1] Proceedings, *Am. Soc. Test. Mats.*, **21**, 1154–56 (1921).

It is possible, by the use of larger capillaries and higher pressures, to examine mixtures of clay and water, in which the proportion of water is a great deal less than that shown in Fig. 2. This method measures the resistance to plastic flow through capillary tubes. The Bureau of Standards is now investigating the theory of plastic flow of clays through capillary tubes and hopes to publish something additional in the near future.

Conclusions

It is evident in surveying the methods brought forward for measuring this fundamental property—plasticity, that none of the methods are perfectly satisfactory. It seems that it is a resultant of two factors or perhaps more. If it be true that there are two or more essential factors which determine the plasticity of a substance, then there can be no true unit of plasticity. In most of the methods brought forward the authors have attempted to express their results in some unit or number which is supposed to define the condition of the material. Bingham's conception of plasticity seems to be the most rational one of all. The greatest difficulty seems to be in defining the term "plasticity" and then sticking to that definition when attempting to measure that property. There is great need for more efficient methods of measuring "plasticity" and a clearer understanding of the factors which influence it. Plasticity, to the technologist, is in about the same category as the term "colloid," to the chemist.

Table I

Plasticity, as defined by Mellor, resolves itself into two factors, *viz.*, (1) the resistance that a clay offers to changing its shape, and (2) the amount of deformation a clay can suffer without cracking.

Method of measuring plasticity	Property actually measured, units	Remarks
1. Ashley dye-absorption method	Absorptive power of clays for dyes Unit-grams dye absorbed from standard dye solution	This is an attempt to measure the colloidal content of clays, but as all colloids do not have the same absorptive power for the same dye, it measures the absorptive power of colloids present and not the colloidal content. It is yet to be proven whether or not the colloidal content is an index of plasticity.
2. Stringer and Emery method	Measures two factors of plasticity as defined by Mellor "Plasticity units" (empirical)	It is difficult to obtain concordant results and method is unsatisfactory.
3. MacMichael torsional viscosimeter	Viscosity of liquids by a torsional balance Unit — the MacMichael degree	The method is not applicable to testing of clay slips as they behave as plastic solids and not as viscous liquids.

Table I (*Continued*)

Method of measuring plasticity	Property actually measured, units	Remarks
4. Emley plasticimeter	Property of retaining water and deformation under pressure Unit—"Plasticity figure" (empirical)	This instrument measures only one of the factors of plasticity.
5. Bingham plastometer	Resistance to plastic flow through capillary tubes	Method based on the definition of a plastic substance as given by Maxwell. This theory of plasticity seems more rational and has a wider application than that usually given by ceramists.
6. Bleininger efflux viscosimeter	Resistance to flow through an orifice under a single uniform pressure	This instrument measures the flowability of a slip, and is not applicable to slips of low water content.
7. Atterberg method	Range of water content over the workable stage Unit — "Plasticity number"	It is Atterberg's contention that the wider this range the more plastic is the clay.
8. Various other methods such as Vicat needle test, A. Brongmat's wad-box, P. Jachum's bending test, and K. Dummel's spiral test	Measure deformation	These instruments measure only one of the two components of plasticity.

LAMINATION, DISCUSSION OF CAUSE AND CURE

By J. J. Fred Brand

ABSTRACT

Discusses types of laminations, *differential* and *interfacial;* the volume relations of clay and water in pugged clay; laminations produced in auger machines; effect of die on lamination; effect of pugging; effect of working upon the character of clays; conclusions.

Lamination and dryer difficulties are the most serious and baffling problems of the clay worker. Losses due to lamination and in drying are great, not only in terms of ware totally destroyed, but also in decreased quality; thus, if not rendering otherwise satisfactory clays entirely unavailable, restricting their use to the lower grades of ware.

Two Types of Lamination.—Lamination refers to the faulty structure in which one or more planes of cleavage occur between layers of formed clay. It may conveniently divide into two forms; first, that which arises from the differential flow of the clay through the machines and which may be properly referred to as *differential lamination;* and second, that which results from an imperfect union of formed masses of clay, *interfacial lamination.* The former embraces the so-called die and perhaps the repress lamination and the latter, auger and core-bridge lamination.

Differential Lamination.—In all processes where pugged clay is made to flow under pressure, the differential type will be produced to a greater or less degree, die lamination in the molding machine, and repress lamination in the repress. While it may not always be apparent in the product, yet it can usually be seen at some stage of the molding process, varying largely with the character of the clay, the pressure applied and the resistance offered to the flow of the clay. This type, when well developed, presents a scaly or lamellar structure, the planes of cleavage separating thin strata or layers of clay.

Interfacial Lamination.—Interfacial lamination is peculiar to wares made by stiff-mud machines which are equipped with either, or both, augers and core-bridges. In this the planes of cleavage are few compared to those of the differential type and occur at less frequent intervals separating thick sections rather than thin layers.

When both the differential and interfacial types are present in the same piece (as in ware from an auger machine) it is not at all times easy to distinguish between the two. Usually, however, there is less bond between the sections of the interfacial type than between the scales of the other, and under severe drying conditions the piece is apt to fail first along the lines of interfacial lamination.

Core-bridge lamination results from the inability of the clay to properly unite after having been separated by the yoke which sustains a core. Thus this type is peculiar to hollow-ware.

Repress lamination may be attributed to a differential flow of clay in the mold along planes other than those produced by the primary machine. Ordinarily this form does not present the scaly structure of that produced by the differential flow in the molding machine.

Volume Relations of Clay and Water in Pugged Clay.—Clays are made up of varying percentages of a variety of mineral particles and aggregates, ranging in size from those which require a further reduction to those that are sub-microscopic. When water is added to such a mass, a portion is adsorbed by the grains, another portion occupies the voids between the grains, thus in effect serving as a filler. This is generally known as pore water.

Another portion occupies the minute spaces between the clay grains and pools of filler water and forms the medium through which the attractive forces act to bring the mass together. Proceeding on this assumption, there is now formed between the grains and pools of filler water, a system of capillary channels of equal area throughout the mass. This portion may be referred to as capillary water. The ability of the moist mass to retain its shape after molding is largely if not altogether due to the attractive forces acting through this portion of the water. The mass is now at its maximum density, any addition or removal of water causing an expansion. At this stage the mass is incapable of taking up additional water without the aid of an outside agency.

To give the mass flowing qualities such as are demanded by stiff-mud machines, a final addition of water is necessary. Its introduction causes a distension of the capillary channels and, with them, the mass. It decreases rigidity by its action as a lubricant. This portion may be referred to as water of moldability or water of distention, or in the drying as shrinkage water.

Granular clays which contain considerable quantities of filler water naturally permit the use of less water of moldability than those clays which, because of a lower content, possess greater initial rigidity. Thus it is impossible to obtain as good flowing qualities in the former as in the latter without encroaching upon the standing qualities of the mass.

In a properly pugged clay, the layer-like water distended channels, which criss-cross in every direction, would be of uniform thickness; each layer or channel presenting its edges to the surface of the mass in ridgelike protuberances so that in the bringing together of two masses of wetted clay, the conditions should be ideal for their perfect union as nothing is involved except the sticking together of what to all practical purposes are two wetted surfaces. It would seem that the advantage would lie with the plastic clays, since in these the channels are more numerous and consequently least tolerant to lines of cleavage, yet both the molding and drying difficulties have multiplied very rapidly with plasticity. In fact the more plastic clays have been wholly unadapted to the manufacture of those wares in which the structural qualities are vital.

Laminations Produced in Auger Machines.—To form a clear conception of the effects produced, let us assume a machine having a perfectly fitting auger, being full of clay and in motion with the die closed. As there is no possibility for the escape of any clay from the machine, there can be no forward movement, consequently that portion of the clay within the influence of the auger must rotate with it. If now an opening be made in the die, allowing the escape of only a portion of what the auger could deliver (the condition under which auger machines operate), then one of two other things must occur: (1) either a part of the mass will stop rotating and move toward the opening, while the balance continues its rotation, or, as is more likely, (2) the whole of the mass rotates while moving forward. The rotation is greatest near the auger surfaces, while the forward movement is greatest in the portions farthest away. This results in a differential flow of the clay and in the formation of differential laminations in the threads of clay within the auger. (Fig. 1*a*.)

Obviously this differential twisting continues after leaving the auger, gradually abating, however, as the mass recedes from the auger. Between the auger and die we have a zone in which the clay is rotated at many different speeds. This results in the breaking up of the laminated structure previously formed in the threads, and in the formation of a new structure (Fig. 1) the cleavage planes of which stand in a position paralleling the face of the auger and arranged helically around its axis. Among the lines so formed there may be found at intervals those which mark the surfaces of the clay streams which were produced within the auger.

The polishing effect of the auger upon the clay has often been given as a cause for auger lamination. It is obvious, however, that these polished surfaces cannot withstand the differential rotation which obtains between the auger and die. Close inspection reveals that they are roughened just as they leave the auger and come into contact with the preceding coil which is rotating at a slightly slower speed.

As the clay mass moves through the die, the shape of the laminated sections becomes modified, the extent of which is governed by numerous factors, among them: (1) the capacity at which the machine is being operated, (2) the relative capacity of the auger and die, (3) the design of the forming members, (4) the character of clay, (5) the state of its temper, (6) the flowing qualities, (7) the resistance offered to the movement of the column by the cutting mechanism, etc.

Ordinarily, however, there is a forging ahead of the center portions of the column, which is more pronounced, other factors remaining the same, when the supply of clay is ample than when low, forming the laminae which are of a saucer shape near the auger, into a series of

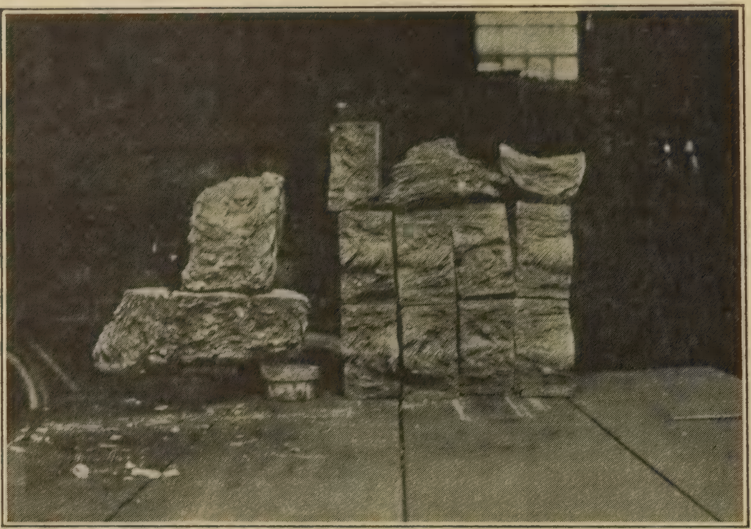

FIG. 1*a*.—Group showing Figs. 1, 2 and 3.

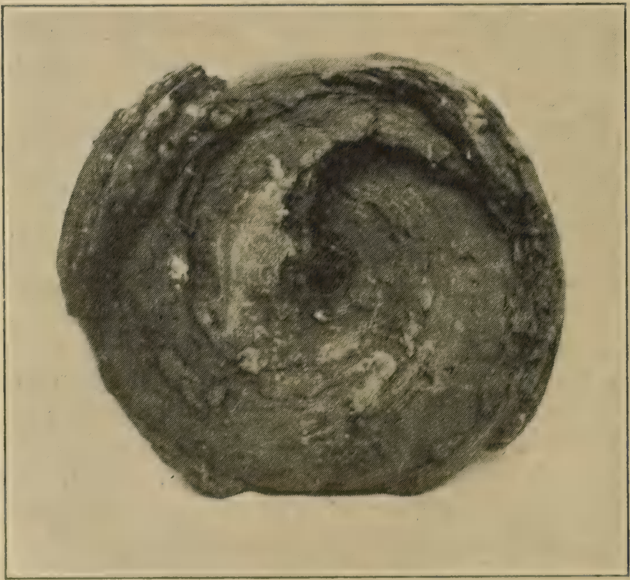

FIG. 1.—Section taken in front of an auger showing an auger lamination plane to good advantage. Cleavage planes near the edges result from differential flow.

telescopic sleeves or cones. The resulting formation perhaps never extends to the center of the clay column on account of the flow of clay which fills the void left by the auger shaft.

Effect of Die on Lamination.—Except for the abrupt change from the larger circular throat to the smaller most generally rectangular-shaped die, it is not probable that the walls of the forming members exert the influence that has been generally presumed. It has been said that the clay flows with greater ease upon itself than upon the metal parts of the die, and that this gave rise to differential flow causing the so-called die lamination. That clay does not flow upon itself with greater ease, especially in the case of a well-lubricated die, is shown by the fact that while a smoothly worn auger barrel lining is worthless to keep the clay from floating with the auger, a corrugated lining which immediately becomes clay-plastered, has a high degree of efficiency.

Fig. 3 shows a piece made while the supply of clay to the auger was low. It will be noted that except as the laminae have been crimped into a zig-zag or herringbone effect, they stand as originally formed. That even the outer surfaces were not affected by reason of having been in contact with the metal parts of the die or forming members is shown by the fact that the lay of the laminae is against the flow.

Since differential flow results from the resistance encountered in the molding, the unitiated might conclude that the proper course would be to select a plastic free flowing clay, or develop that quality to the utmost in the clay at hand and reduce as much as possible the frictional surface of the forming members by shortening the distance between the delivery end of the auger and the point where the clay leaves the machine and to introduce lubrication at a point as near the auger as possible. The most that would have been accomplished by such measures would be reduction of pressure and differential flow.

Machines designed on these theories have been successful only with the most easily flowing clays while those designed on quite opposite theories have been more generally successful. This is especially true in the working of the more gritty shales and clays, which offer greater resistance to passage through the machine.[1] In the working of these, instead of doing the most to promote their easy flow just the opposite has been done. Not only is there ordinarily a greater difference between the capacity of the auger and die than in machine operating in plastic clays, but we often find extra long dies and throats in use which cannot but increase pressure and resistance and with them, differential flow. If we compare the products of these machines such as paving brick with that of the sewer-pipe press in which there is no twisting, we will find in most cases that the former has much the better structure, regardless of the fact that ordinarily clays of the same

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[1] Bleininger and Ross, *Trans. Am. Ceram. Soc.*, **16**, 392 (1914).

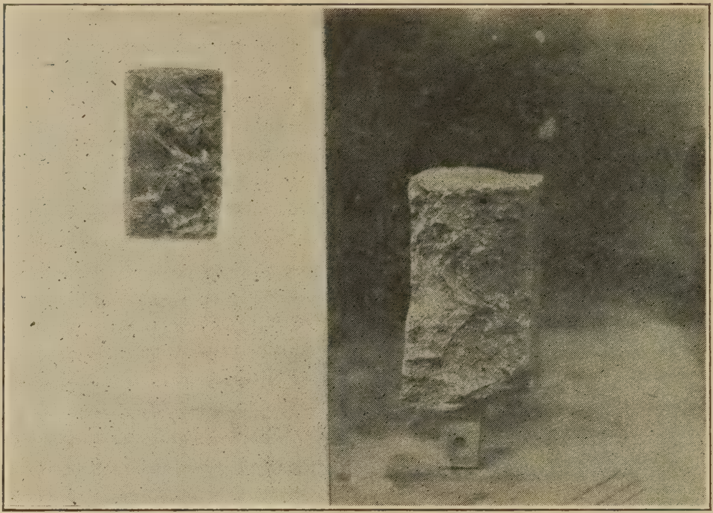

FIG. 2.

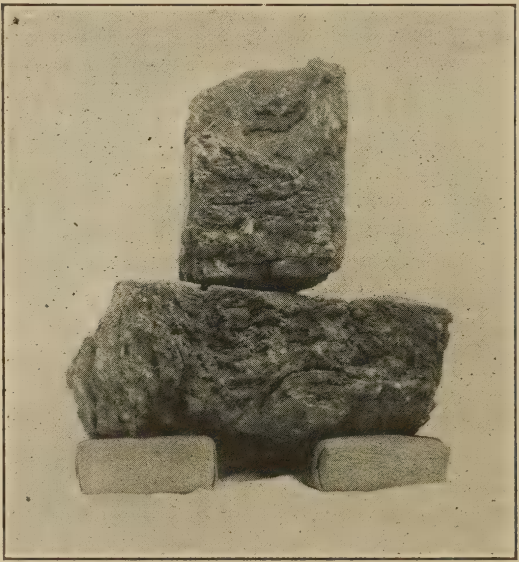

FIG. 3.

general character are used in each, and that the latter usually possesses any advantage which the wet-pan confers.

Add to the above the uncertain effects of various degrees and methods of pugging, one becomes engulfed in a series of complications. In the one we do the logical thing by increasing the capacity of the forming members and secure results in the direction of those anticipated, while in another situation we apply the same reasoning and the same methods that are positively disastrous. But by doing the seemingly illogical thing at a most illogical time we may succeed in not only practically removing the ill effects due to differential lamination, but also many of those arising from auger lamination.

Effect of Pugging.—The generally acknowledged superiority of the wet-pan as a pugging device over the common pugmill, because of the better results obtained, has led many to believe that the elimination of lamination was only a question of sufficient preparation, yet one can not but be impressed by the structural qualities of the older stiff-mud products, commonly made through an unlubricated die, of clays which are now considered the most troublesome and which received their preparation in no better device than the soak-pit. A method of tempering, which if more excellent than modern devices, does not derive its qualities because of any ability to produce a more intimate mixture of the various minerals present with water.

The writer is familiar with a plant which grew from a very crude one to a modern institution. The method of manufacture in its early days consisted of spading the clay from the field into carts and, after the addition of one or two buckets of water, it was taken to the plant and fed directly into an auger machine. Ancient methods perhaps, but there was no lamination, a fact attested to by the bricks in the old walls. Later after the plant had become modernized, lamination became a very serious problem. The older heads always insisted that the troubles came with the pugmill.

Figure 5 shows several pieces made of clay which passed through a disintegrator and smooth rolls and then pugged to soft-mud temper in a soft-mud machine in which it laid for seven months afterwards. When taken out it was of a temper which permitted its molding in an auger machine through which it was run. Comment is quite unnecessary.

On the other hand, witness the value of that action obtained between the auger and die, as has been noted elsewhere in the working of the gritty clays. That the value of this pugging action is not confined to any particular type may be shown by the fact that if we return any clay to the machine often enough, differential lamination will largely if not altogether disappear, depending upon conditions which will be touched upon later. But because of the fact that the clay comes into contact with the auger each time, auger lamination is not effected to a marked degree. The same results, except that auger lamination would also be effected, could be procured by sufficiently lengthening the distance between the auger and die. While the number of returns to the machine or distance between the auger and die to obtain a given result will vary widely with clays of varying characteristics, yet the difference in the character of the clays is not fairly represented by this variation. The flowing qualities of the clays necessarily enter as a factor. Obviously, an easy flowing clay does not receive the same treatment in a machine of a given design as a clay which offers greater resistance. Power expenditure would perhaps serve as a better standard by which to measure these characteristics. It may be added in passing that this treatment, that is, returning the clay to the machine several times in succession, causes clay to become short, instead of developing plasticity.

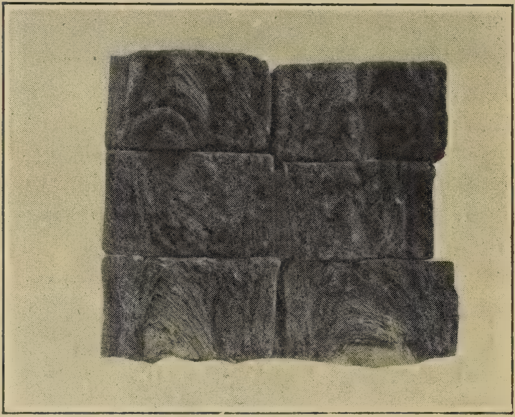

FIG. 4.

The remedial influence of differential flow is further shown by the fact that either or both differential and auger lamination are often more pronounced in the earlier stages in the machine or molding than in the product of the die.

If differential flow is a large factor in the cause of differential lamination, how may this fact be reconciled with the fact that it also acts as a remedy?

Take a given clay and run it through a given machine. We will assume that a mass of relative thick layers or scales of clay separated by comparatively few lines of cleavage are produced. We return this mass to the machine and run it through again, giving us more lines of cleavage with a corresponding thinning of the clay layers; we repeat the operation causing more lines of cleavage and thinner plates of clay and so continue until it is no longer possible to subdivide the clay layers. We no longer have alternate lines of inordinate strength and weakness and the resulting effect is about as would be obtained by the use of a clay of lower plasticity under other conditions. In other words, the mass would be so thoroughly laminated as to be harmless in effect.

Such success as has been obtained in the elimination of the difficulties incident to lamination has resulted from measures which either increased or decreased the resistance to the flow of the clay through the machine. The most far-reaching results have been attained by the first, as the method is particularly adapted to the more granular clays. The same holds true in situations where it is possible to add granular material to the more plastic varieties. The method, however, requires that everything possible must be done to bring about a maximum resistance; otherwise only an intermediate structure is possible.

In the working of the easy-flowing clays in which the structure develops slowly, the procuring of a satisfactory state of homogeneity is ordinarily impossible because of the limitations of the machines. In these clays we would restrain as much as possible the formation of cleavage lines. To this end we would use a machine which offered the least possible resistance to the flow of the clay.

But why can not a machine whose power is measured by tons do what can be done between the thumb and fingers? Why should the mere assembling of clay granules around a center point or in any other imaginable position cause lines of cleavage separating layers of clay thicker than the granules? Certainly none of them have any choice as to which other granule it will or will not unite. That the fault is not fundamentally in the nature of the machine is shown by the operation of an auger machine which was fitted with a hollow-ware die. In this the die was placed about twenty inches from the face of the auger and produced ware of a very poor structure as shown in Fig. 5, lamination being produced in the long extension as outlined elsewhere. Due to the method used in the preparation of the clay, it often became necessary to remove and clean the die. It was always found that that portion of the laminated clay which had been left in the extension near the auger would come through the die without lamination.

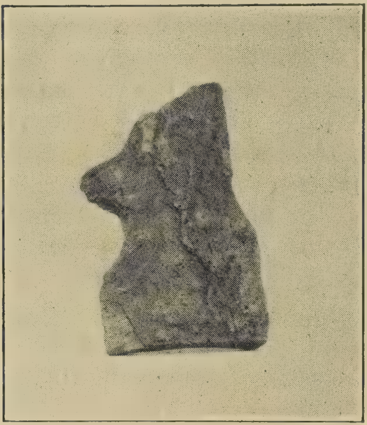

FIG. 5

It has been advanced that the glutinous or colloidal character of clays promotes the formation of slippery surfaces, first by the effect of the auger, and again by the flow of the clay upon itself. As to the first, it has already been noted how the smooth surfaces of the clay streams are destroyed by the differential twisting as they leave the auger and, if differential flow destroys such a surface, it cannot produce one. In the finished ware, the surfaces of the laminations never present any but a decided roughness, at least as rough as the granular character of the clays permit, never a slipperiness. On the other hand if these surfaces were smooth and slippery we would have all the more reason for expecting them to unite; for if we take two sections of the polished clay streams from the auger or two pieces of ware from a dry die even, and bring them together with a slap they will unite perfectly. But if these surfaces are only slightly marred, they will not unite.

The addition of grog or other granular material to plastic clays has been used with some success as a palliative, but certainly not because its granular character served to prevent the clay from slipping upon itself, for the clay no matter what its physical character may be, must twist or pass through the forming members without friction.

But whether or not the twisting or differential flow causes slippery surfaces, and whether or not the clay streams from the auger escape into the column with their smooth surfaces, in either or both cases the surfaces should be either smooth or rough. Why, then, does auger lamination so persistently remain under conditions which mitigate or perhaps entirely eliminate the effects of differential lamination?

Slow drying has a wholesome effect—and this when the conditions would seem the least favorable; for the union of the laminations can not be completed until maximum shrinkage has been reached and the clay to all purposes has become dry. It would seem that the most favorable moment for their union passes after the clay has passed the machine and begins to dry.

Effect of Working upon the Character of Clays.—That the ordinary methods of working have a marked influence upon clay is shown by the following:

Plastic clays direct from the fields, when in a condition approximating a stiff-mud temper, slake very slowly in water. The same clay after not too thorough pugging disintegrates rapidly into larger units, which in turn slake slowly.

After passing through the auger machine, disintegration, while no more rapid than before, breaks up into smaller units, which also slake slowly. After several times through the machine, disintegration approaching slaking is rapid and thorough, the mass immediately breaking up into very small units.

A significant circumstance touched upon above is the fact that the clay after several times through the auger machine becomes short, the cause of which can not be attributed to any physical change in the clay itself.

If anything, such intensive working should tend to develop plasticity. The swelling of the clay-bar as it leaves the die does not represent a relief from true compression.

The foregoing, brought out in numerous experiments and observations, convinced the writer that neither the character of the clays nor the kind of machines used formed a satisfactory basis for explaining the difficulties attending the molding and drying of clay wares.

Effect of Air.—After eliminating these as probable causes, search was continued in other directions. Air as a possible cause was suggested by the fact that the ware blistered badly as a column left the die. An examination showed that the blisters were formed by the outer layers of clay which left the mass at cleavage lines. Immersion of a brick in water showed measurable quantities of air coming from the piece as it disintegrated.

Desiring to ascertain the approximate quantity contained in a newly made brick measuring 9″ x 4″ x 2½″ an apparatus was arranged which would permit the dissolving of the piece in water and the measuring of the air thus set free. To this end, a pot-shaped shell of a steam trap with a removable cover was connected to the burette of an Orsat apparatus. A gage glass open at its upper end was fitted to the side of the shell; this for the purpose of keeping the water in it at a constant level throughout the experiment.

The method of operation consisted of filling the burette with water in the usual manner. The shell was filled to such a height so that when the brick was introduced, the water would overflow through the gage glass. After the piece had been immersed, the cover was quickly put on and the stopcocks to the burette opened. By this method, which seemed of sufficient accuracy, for our purpose, we found as much as 30 cc. of free air in several samples.

Lacking, at the time, the means to put the theory to test under conditions which would approximate actual practice, a quantity of laminated ware from the off-bearing belt was made into a slip and boiled by steam to remove the air. This was then cast into molds and allowed to dry to a stiff-mud temper, after which it was run through the auger machine.

The column came through without the slightest traces of lamination, as the sample showed. The clay was then returned to the machine several times, until it began showing a few lines of lamination due to a re-incorporation of air. But it was not until the clay had been grated through a screen and then wadded into balls, in order to more thoroughly inclose air, that lamination reappeared to a degree approximating its regular form.

The drying qualities of the airless unlaminated pieces were all that could be desired, as neither that which was run through the dryer with other ware nor that which was placed upon the bare coils of a steam rack dryer suffered the slightest deterioration in structural qualities.

These results led to the construction of a small machine which would permit the use of a vacuum pump, thus approximating commercial conditions. Our first attempt in which we tried to remove air from a tempered mass resulted in failure, so far as commercial practicability was concerned. The difficulty did not reside so much in the obtaining of high vacuum conditions in the presence of moisture, as in the fact that as soon as vacuum conditions were obtained, the outer portions of the clay pieces became very dense and tough, thus preventing the removal of the air from the interiors. Somewhat better results were obtained by finely disintegrating the clay through a screen, but even by this method from twenty to thirty minutes were required before any marked effect was registered.

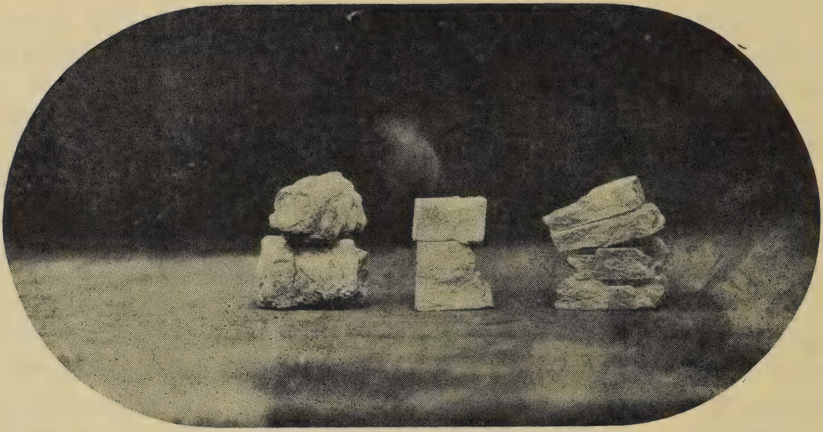

Fig. 6.

Further experiments developed the fact that commercially practical speed and results were procurable by removing the air from the clay previous to and during the tempering process.

Clays so treated become very tough and dense and practically, if not altogether, immune to the slaking action of water. This is true not only of the naturally sticky clays, but in a large measure also of the leaner varieties. This indicated to the writer that the absence of air in the interior of the clay mass and the pressure of the atmosphere play an important part in the phenomena of plasticity.

The clay used in these experiments was one of those limey varieties of glacial origin found near the shores of the lower lakes, used extensively in the manufacture of soft-mud brick. The more plastic portion of it was only fairly well adapted to the stiff-mud process in the manufacture of brick and hollow-ware whose cross-sectional areas did not exceed 5″ x 8″. Larger pieces would collapse before reaching the cutter. Its tendency to laminate and crack in drying was frightful. The ware was very difficult to handle from the off-bearing belt on account of the shortness of the clay, though it exhibited a fair degree of plasticity before pugging. However, when tempered and pugged under vacuum conditions, it showed a surprising degree of tenacity and ductility. Instead of the characteristic rottenness as under the ordinary methods of working, it required some strength to pull apart a bar measuring $1^1/_2$ x $1^1/_2$″, the clay drawing down to a very small area before separation.

"Joint" clays treated by the vacuum process survived the most severe drying conditions. Pieces as large as walnuts stood, without cracking, a temperature which was sufficiently high to also expel the chemical water. A piece about the size of a half brick was dried without cracking in a bake oven which was previously heated to a temperature above 200° C, though the same clay, after a few moments' working by the hand, would shatter under much less severe conditions.

Conclusions

Clays which have been tempered and pugged in air contain varying quantities of occluded air, some of which become divided into blebs small enough to be contained in the water-filled channels without causing their distension or a separation except in local areas. The remaining portion, however, occurs in pockets of a larger volume than can be contained in local areas at low pressure. When such a mass is brought under pressure as in the auger machine, these larger pockets, together with the clay inclosing them, become flattened into alternate layers of clay and air.

If the clay be of the smooth, plastic, free-flowing type, offering a minimum resistance to its passage through the machine, the laminated mass escapes into the column with no substantial change in structure, except as modified in its passage through the die. If, however, it is returned to the machine several times in succession, it will result in the gradual breaking up of the heavier air layers into thinner and more numerous layers and finally into blebs which can be contained in the pores without causing their distension or a separation of the mass, provided, of course, that an excessive amount of air is not present to begin with. In such a case, reworking avails but little.

While the occluded air in a satisfactory state of diffusion does not affect the normal diameter of the pores or channels, its presence is nevertheless a source of weakness; hence the shortness of much pugged clays.

If the clay be of the coarse granular type, one which offers a maximum resistance to its passage through the machine, the more efficient pugging thus obtained may be sufficient to diffuse the air and destroy the initially formed structure during a single passage through the machine. In this type much pugging does not cause the same comparative loss in plasticity. This is due to the fact that these clays contain more of the water-filled void spaces, which offer lodgment to a greater portion of the air at points where its weakening influence is at a minimum. Thus if the quantity of air present in the beginning is only sufficient to displace the filler water, then intensive working under pressure would effect an actual cure. Otherwise, we would have, at best, a distribution of the weakening influence throughout the mass.

Auger lamination is due to that air which has been set free by the friction between the auger surfaces and the clay. This air collects at the tips of the vanes and its only avenue of escape lies between and with the clay-streams moving toward the die. A situation of the same character obtains at core-bridges, causing core-bridge lamination. Repress lamination is caused by air which is in part set free in the breaking apart of the mass and partly by the movement of one section upon the other while under pressure in the mold.

The layers of free air besides acting as walls which prevent the clay from uniting also act as lubricants which are largely responsible for any differential flow as well as affecting the efficiency of the auger.

The swelling of the clay bar as it comes from the die is due to the re-expansion of the inclosed air.

Tempered clays free from air slake very slowly, while those through which air has been thoroughly diffused slake rapidly, requiring only minutes as against weeks or months as in airless clays. If the air has been less thoroughly diffused, the mass falls apart rapidly, but the resulting units, being airless, slake slowly.

In the experiment with the hollow-ware machine, the air was given an opportunity to escape from that portion of the clay which was left in the throat of the machine. Being airless it did not laminate, neither did it slake rapidly.

Incorporated air affects the drying qualities of clays in at least three different ways. First, its presence lowers the strength of the mass-making it impossible for the attractive forces to move as great a load without causing a separation as would be otherwise possible. Second, the air in any state of diffusion may sufficiently expand under the heat of the dryer to cause ruptures. This is probably a common cause for breakage among the feebly plastic types. Such a clay was the one referred to which cracked in saturated atmospheres at comparatively low temperatures. Third, and perhaps the most common cause, is the hindrance which the air blebs offer to the ready egress of the water. In this too, the inevitable expansion of the gases due to dryer temperatures adds to the difficulties. For to entirely obviate the losses from this source, it is not alone sufficient to bring the blebs to such a size which will permit their ready escape to the surface at normal temperatures, but due allowance must also be made for the expansion.

It is evident that after the air has been broken up into blebs by intensive working, in the molding machine, to such a size as may be contained in the pores without exerting a pressure at the lower temperatures, compensation for the higher temperatures becomes increasingly difficult, if not wholly impossible from a practical standpoint.

Assuming that the blebs are unable to assume a spherical form in the narrower sections of the channels, as soon as drainage conditions are established they will move until they reach the water-filled void spaces where they are afforded a better opportunity to form into spheres. If the resulting bubble is only large enough to displace the filler water, it can not effect the drying quality of the mass. But if it also displaces a part or all of the surrounding water of moldability, it becomes an obstruction by narrowing or entirely closing the channel except for the thin film of capillary water, which must then assume the burden of supplying the water to the surface. Not being equal to the task, the outer portion of the mass dries and the piece cracks.

It is evident that after the blebs have come to the spherical form in the wider portions of the channels, they can not be dislodged unless they be again elongated to allow their passage through the narrower sections. Since the force available for this purpose is practically nil, the blebs remain as barriers until the water between them and the surface has been removed.

Thus it seems that the presence of air offers a very satisfactory basis for explaining the peculiar behaviors of the various clays. The removal of the air from clays prior to and during the tempering and pugging process which has been made subject of Letters Patent offers great possibilities not only in improved products in clays now worked, but also in the utilization of many broad acres of clay, which though well situated with reference to markets has hitherto been unavailable because of the difficulties attending their manufacture.

J. J. Fred Brand
Roseville, Ohio

Discussions

By W. D. Richardson:—The paper presents a close study of a subject in which all brick manufacturers are interested and of which we all need to know more.

The treatment is a valuable contribution and creditable to the author. Even in reading his paper one becomes, as he states he was in his investigations, "engulfed in a series of complications." This comes somewhat from the fact that the conditions and movements inside of an auger machine between the end of the auger and the mouth of the die must be imagined, as they can not be seen.

The whole subject is one that should be given such a thorough systematic investigation, with a variety of clays, as is practically impossible by a brick manufacturer himself, and his experience must necessarily be limited to the clays with which he has to deal.

The matter should be referred to our Research Council for further study and investigation.

A radical statement in this paper is that differential lamination is not caused by differential flow, and that the center of the mass of clay in the nozzle of an auger machine does not move faster than the center though this statement conflicts with a later one.

This statement does not conform to general observations of practical men. Whether the differential flow is due to difference in the friction between the clay and the iron and between the clay sliding on itself or to the greater pressure exerted by the auger on the center of the clay mass, it has been generally observed that the central portion of the clay does forge ahead of the sides, and it is generally believed that this is the primary cause of differential lamination.

The author thinks he has proved his point by the fact that when the barrel lining of the machine becomes worn smooth the clay will turn or float with the auger. But this is not logical, since it leaves out of consideration the compressive force of the auger on the clay in front of the auger.

Another radical statement in the paper is that auger lamination is not caused or influenced by the helical rings of clay passing off of the ends of the auger being polished or slicked by the surface of the auger or at least that this slicking is not a primary cause of these rings of clay not uniting thoroughly in the die. It is fair to assume, however, that the author would admit that this slicking, which is more pronounced in fine-grained plastic clays, prevents the escape of the air between these surfaces and thereby prevents their bonding together.

Undoubtedly, occluded air does prevent the bonding of clays in a strong homogeneous body and is a cause of blisters or laminations, of spalling or perhaps dunting, as hand molders of glass pots or blocks or other clay bodies well know.[1]

Mr. Brand's studies on the effect of air in clays in producing lamination and cracking in drying are the most valuable part of his contribution and he should be induced to write a paper on this theme alone giving a more detailed account of his experiments, with photographs or drawings of the apparatus employed, citing also the patents that he refers to and showing whether any of these are of practical application in brick manufacture.

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[1] Simcoe, *Trans. Am. Ceram. Soc.*, **11,** 343 (1909); **12,** 376 (1910).

REPLY BY J. J. FRED BRAND:—But for the presence of air within the clay mass, differential flow would not cause differential lamination. Differential flow, however, is a factor and without *it* there would be no differential lamination. We can see that in many of the hand-made soft mud bricks which show, upon breaking, pockets and holes which undoubtedly contained air at the time of molding, but because of the fact that there is practically no differential flow during the molding process these do not become flattened out as in auger machines.

The impression I wanted to leave was that differential lamination was due not so much to the differential flow arising from the forging ahead of the center portions of the column, as to the differential twisting which obtains between the auger and die. For most part the secondary differential, which obtains as the clay enters and passes through the die, little more than modifies the shape of clay layers formed near the auger. Clay does not slip on itself with greater ease than upon a lubricated die. Any forging ahead of the center portions of the column is rather due to the cushion of air between the layers of clay. Ordinarily there is a forging ahead of the center, but Figs. 4 and 5 show that this is not always the case.

When the barrel of an auger machine becomes worn smooth there is a serious loss in capacity. This is due to the fact the clay in the auger turns with the auger instead of moving forward. The corrugations in a new lining do not at all come into contact with the moving clay, except at the tips of the corrugations perhaps, which the auger may touch and keep clean. The thing which prevents the moving clay from turning with the auger is the clay plastered lining. Admitting, however, that the clay nearest the corrugated lining does move forward instead of acting as a plastered surface, even that would not show that clay slipped on itself easier than upon metal. For if it did, a break would certainly occur in the clay which is between the auger and lining (augers never fit closely) and the two surfaces would slip on themselves.

The auger does slick the clay ribbons of the auger, but the differential twisting which obtains in the throat of the machine destroys these slick surfaces. In the fine-grained clays we have less of the filler or pore water than in the grogged or naturally coarse clays, hence the air can not lose itself in the spaces occupied by this water to the extent as in the latter. It must then displace water of moldability which causes a separation of the mass. In other words, if there is enough filler water space in the mass to carry the occluded air and means at hand for diffusing the air into these spaces we do not have a separation of the mass in the way of laminations.

One can not of course see the clay on its way through the machine but by adding foreign materials to the clay (the writer used oats) and then stopping the machine when full of clay, he can follow very closely the course of the clay through the machine. The oat grains arrange themselves parallel to the direction taken by the clay with the base of the grain ahead.

BY E. LOVEJOY:—Mr. Brand gives us new names for lamination, namely, differential and interfacial, the one caused by slippage of the clay on itself, commonly termed die lamination, and the other a junction of cut masses of clay, which we are accustomed to call auger lamination. He includes in the latter term the union of surfaces cut by core-bridges which is not consistent with the meaning of the word lamination. The auger lamination is distinctly a union of cut surfaces and may be called interfacial, but with it there is some differential flow which develops the cone in cone structure. I am inclined to stick to the old terms. The repress lamination is not clear to me. We have always assumed that the effect of repressing was simply to buckle and separate the machine laminae. We never recognized any lamination in pressing stiff-mud shaped bricks, the mud for which was batted out by hand.

If I understand his statement in regard to the water content in pugged clay, I can not fully agree with him. A granular clay will take less water in pugging than a colloidal clay, but in the flow through the die one can not determine the rate from the water content. The character of the clay in its adhesive and cohesive properties is a big factor in the flow, considering the movement of the mass from the back of the machine to and through the die. The strongly adhesive, and correspondingly weak cohesive clays will be more difficult and flow at a slower rate then the clay of a contrary character.

I agree with him that in every instance there is more or less rotation of the mass of clay with the auger and I have experienced the effect of a smooth barrel as he suggests, and had the greatly reduced output in consequence.

I have illustrated this by a bolt and nut. Turning the bolt will not advance the nut, instead the nut turns with the bolt, but if the nut is held and prevented from turning, it will be advanced in turning the bolt. Similarly if the clay slips easily in the barrel of the machine it will turn with the auger and not advance through the die. One might conclude from this that the adhesive clays would be more favorable to flow than the cohesive clays, contrary to the statement above given, but not so, because there is always a clay lining in the barrel and it is the clay slipping on itself that causes the turning with the auger. We get adhesiveness by corrugations in the barrel.

The usual simple explanation of auger lamination is that the auger cuts the mass of clay spirally and packs these spiral slices into the die and they are drawn out into the cone in cone structure by differential flow. This is good enough for me, but I accept the very likely possibility that a firm union of these slices may be prevented by air.

Mr. Brand rejects the common conception of die lamination—that is, differential flow in consequence of die friction, but it is not clear to me that he offers any other explanation.

In pugging, I agree with him that increased pugging does not lessen lamination. It does develop the inherent qualities of the clay that result in a stronger and better formed ware and this is the purpose of wet-pan preparation and not the reduction of lamination.

The soak pit tempering which he belittles is, in my opinion, superior to our modern rapid and continuous machine preparation. The general abandonment of its use is due to its inadequacy in modern operation instead of lack of preparation.

Grog, as he states, is successful in lessening lamination, but he rejects the usual belief that the effect of grog is to prevent slippage of the clay on itself, and in this I can not concur. Grog not only reduces the slippage but also roughens the surfaces of the laminae and thus increases the possibilities of a firm union, besides serving as binders to hold the planes from separating under drying shrinkage strains.

The main feature of Mr. Brand's discussion is the effect of included air on lamination, and I agree with him that it may play an important part in this serious trouble. That the wet clay mass contains air is beyond question. Perhaps all of us are familiar with the air blisters on the surface of machine clay columns, and with the various attempts to overcome the trouble by cutting knives, gratings, etc. A number of years ago several such devices were introduced as a cure for lamination and in some degree with some clays they were effective. The idea was that such contrivances between the auger and the die served to equalize the flow of the clay, but we would still have the "interfacial" lamination which if not strongly united would be as bad as the ordinary lamination, nor could the devices eliminate the unequal flow in consequence of the friction of the die.

However that may be they did improve the product in a number of instances, but extended use showed that the effect in any consequence was limited to a few clays, and the devices fell into disuse. It is likely that the value of the devices was in shredding the clay in the machine barrel and thus permitting the escape of some of the air. With all, or part, of the air removed, the chances of slippage would be less and those of union of the split masses greater.

That included air could easily act as a lubricant to increase the slippage of the clay and prevent the planes from re-uniting is unquestionable, and this part of Mr. Brand's discussion is worthy of serious consideration by the clay workers of the country, who are concerned with the means of overcoming the trouble, and not with the technical data and theories in explanation of the movement of the clay through the machine and die.

REPLY BY J. J. FRED BRAND:—Ordinarily perhaps the repress does merely buckle and separate the machine laminae, in fact the brick would naturally go to pieces along the lines of greatest weakness, especially if the line of weakness coincided with the plane which would be produced in the mold. If a clot of clay full of occluded air is placed in a repress mold which it does not fit too closely, a differential lamination will be produced on account of the differential flow which would obtain during pressure. I once saw a plunger machine making fire-clay shapes measuring about 8″ x 8″ out of a very coarse clay. The bar from the machine, due to the absence of an auger and high pressure, was such that one would say that there was no lamination. Yet when these came from the repress they were laminated badly. The product of the die because of its excellent structure would never have given a hint of what would happen to it in the repress. The horizontal cracks obtained in ware from the dry press at times are certainly a type of lamination due to air.

Mr. Lovejoy's adhesive and cohesive properties of clays are not clear to me, but it seems taking an extreme case, as a so-called colloidal clay would flow through a machine with greater ease than a clayey sand as the other extreme.

The corrugations of an auger barrel always become clay plastered, that is, the moving clay never comes into contact with the corrugations except, perhaps, at the extreme tips. This clay plaster is the thing which prevents the clay from turning with the auger. I say, prevents, this of course is not strictly true, because the clay does turn with the auger to some extent. It, however, is the best thing we have to prevent it.

It has been my observation that the greater part of differential lamination is formed at the face of the auger by the differential twist which obtains there; the pushing ahead of the center portion of the column mostly giving a new form to the laminations already produced. However, there are too many factors involved to say that this is exactly what always happens.

Grog increases pore space or filler water space, which permits air to escape into it and here it cannot cause a separation of the mass. It also increases the friction of the clay in the forming members, and with it increases differential rotation which in turn aids in the diffusion of the air into these pore spaces, resulting in lessened lamination.

Undoubtedly the cutting knives, gratings, etc., which Mr. Lovejoy mentions merely serve to increase friction and with it a better diffusion of the air through the clay mass.

BY R. A. HORNING:—Mr. Brand has brought forward many interesting things concerning lamination. I know of nothing of more importance to the Heavy Clay Products industry than some constructive research on moist clay.

Mr. Brand's ideas on the cause of most lamination have been well founded if he has gone through this as well as his paper indicates.

It will be interesting to note just what will come from Mr. Brand's new thought on the cause of lamination and just what methods will be applied to make it practicable.

By George W. Shoemaker:—I have carefully studied Mr. Brand's paper and have checked his findings against the conditions existing in our machines and our clay column.

His observations and samples can be duplicated in kind if not in degree at our No. 1 plant.

I would comment on his paper as follows:

His observations as to the forms of the lamination in the clay, at the various stages of its passage through the machine, are correct.

These observations tend strongly to establish a basis for his theory of lamination.

It would be worth while for some one with laboratory facilities to try pugging clay in a closed pug directly connected with an auger machine and using low pressure steam instead of water. The writer believes that the proposition of excluding the air by the use of steam is more feasible than that of exhausting the air by means of a vacuum.

PAINTING IN UNDERGLAZE COLORS ON THE BISCUIT

By Frederick H. Rhead

ABSTRACT

This paper describes the more commonly known underglaze colors and gives typical formulae.

The commercial colors on the market are recommended for general use.

The various bodies suitable for this process, white or colored, are described, and the more generally used mediums with methods of preparation are given. The different methods of application and decorative treatment are discussed in connection with both transparent and opaque colors. Comparisons of the technique are made between underglaze painting and oil and water color painting.

Glazing and firing treatment is also discussed. The paper concludes with some notes on historical types.

Underglaze Colors and Their Composition

Underglaze colors are finely ground calcinations of the various metallic oxides together with such materials as alumina, flint, zinc, whiting, etc.

The degree of heat necessary for calcination is determined by the type of color and its composition. For instance, a blue for comparatively low temperature work (cones 1–4) and consisting chiefly of cobalt and zinc need not be calcined to the higher temperature necessary for a cobalt-alumina blue to be used to cones 12 to 18.

As a general rule, in present practice, more brilliant colors are available for temperatures ranging below cone 6. At higher temperatures, especially when exceeding cone 12, blues, greens, grays and blacks seem to predominate, although it is possible to produce clear pinks, crimsons, yellows, lilacs and browns at temperatures ranging from cones 14 to 18 and higher.

Having a suitable formula, the two essentials in the making of reliable underglaze colors are, (1) correct temperature and atmospherical conditions for the calcination, and (2) the extremely fine grinding of the final mixture. It is difficult to state which is the more important of these two. Any variation in the calcining or grinding will result in variation in color and texture. As each color requires an individual treatment it is no simple matter to prepare a wide range palette satisfactory to the decorator. This is why one color manufacturer specializes in pinks and crimsons, another in blacks, another in blues, and so on. Also, as the glaze is an important factor, a certain make of color highly valued by one decorator will not give the same satisfaction to a painter using a different body and glaze.

The following formulae will give an approximate idea of the compositions of underglaze colors used in present commercial practice (Table I). The mixtures are usually sieved dry two or three times, calcined and afterwards well washed and ground. In this discussion, we are not concerned with the actual process of color making. This subject will be dealt with in a future paper.

TABLE I

UNDERGLAZE COLORS

	Blue	Pink	French green	Black	Brown	Yellow	Orange	White	Olive-green
Tin	..	40	..	20	..	30	30	48	..
Whiting	40	15	..	..	..	..	..	..	..
Fluorspar	..	6	..	..	..	..	..	..	..
Flint	..	16	75	..	..	..	..	..	50
Bichromate of Potash	..	2	..	..	..	..	..	..	..
Zinc Oxide	..	..	25	..	40	..	..	..	20
Borax	..	..	100	..	..	..	..	60	25
Ox. Chrome	..	..	20	..	6	..	..	..	30
Ox. Cobalt	150	..	10	50	..	..	..	..	10
Ferric Oxide	..	..	..	10	6	..	35	..	..
Ox. Nickel	..	..	..	20	..	..	..	..	..
Red Lead	10	..	..	..	5	90	100	60	..
Flint Glass	40	..	..	..	..	..	..	..	..
Nitrate Potash	10	..	..	..	..	..	..	..	..
Chromate Iron	..	..	..	120	..	..	..	..	..
Boracic Acid	..	..	..	..	5	..	..	..	..
Antimony Ox.	..	..	..	..	..	60	70	..	..
Feldspar	..	..	..	..	..	..	..	100	..
Lynn Sand	..	..	..	3	..	..	..	10	..
Carb. of Soda	..	..	..	..	..	..	..	..	..

TABLE II

LIQUID UNDERGLAZE COLORS

	Turquoise	Light blue	Dark blue	Green	Dark green	Yellow	Brown	Gray	Pink-gray	Gray-black
Water	100	100	100	100	100	100	100	100	100	100
Glycerin	50	50	100	100	..	100	100	100	50	50
Nitrate copper	30	..	..	50	..	..	..	..	..	..
Nitrate cobalt	..	25	40	..	..	..	..	..	..	..
Nitrate uranium	..	..	..	..	..	100	..	..	..	..
Chromic acid	..	..	..	..	80	..	..	..	..	..
Ferric chloride	..	..	..	..	..	..	100	..	..	
Nitrate nickel	..	..	..	..	..	..	..	120	..	..
Chloride gold	..	..	..	..	..	..	..	..	40	..
Chloride platinum	..	..	..	..	..	..	..	..	..	40

When assembling an underglaze palette, small brush trials should be made showing the colors in light and heavy washes. When the trials come from the kiln, the various stains of same color are compared. Attention should be given to texture as well as color value. Certain colors may be too highly fluxed for some purposes, resulting in flowing and softening at the edges of the wash, or they may be absorbed into the glaze. In some cases this softened effect may be desirable, but its effect must be noted in comparison with the texture of the remaining colors in the palette. For the preliminary palette, it will be wise to select those colors which are clear and firm.

While this discussion is concerned with powder colors, in underglaze work, there is another type of color used to some extent in the decoration of porcelain, and to a lesser extent in faience and terra cotta work. These colors are liquid in form and are solutions of nitrates and chlorides. Typical formulae are as shown in Table II.

These colors are most valuable when flat washes of low tones are desired.

Types of Biscuit Bodies Suitable for Underglaze Decorations

Underglaze colors may be successfully applied to any type of biscuited or baked body, although white, cream, buff and sometimes red bodies are more generally used. If a proper medium is used, it makes little difference whether the body is porous or vitrified.

With few exceptions (the matte blues, light yellows, deep chrome greens, and certain browns) underglaze colors are more or less transparent. Consequently when darker bodies are used, it is advisable to add underglaze white to the colors much as one uses white in oil painting. Or, a ground consisting of white alone, or mixed with some other color may be brushed, sprayed or sponged over the surface, and the decoration applied over this.

Painting Mediums

1. **Water.**—If the body is porous, the colors may be ground in water to a thick paste and used much as one would use water colors. This method is only suitable for direct painting, and considerable skill is necessary if elaborate decorations are required. There is also the danger of rubbing the decoration which will powder at the slightest touch before it is glazed. If the body is very porous, considerable water must be taken up in the brush, in fact the process in this case is like painting on blotting paper. The two chief advantages in using water alone as a medium are, (*a*) it is simple and suitable for direct painting, (*b*) the work can be glazed without an extra firing before the glaze is applied.

2. **Gum Arabic.**—A twenty-five per cent solution of gum arabic with water, and possibly a little glycerine makes a satisfactory painting medium. If too much gum is used there is a possibility that the color or glaze may

blister, even if the finished work is fired or "hardened on" before glazing. It is advisable to make preliminary tests before doing elaborate work with this medium. When gum arabic is used it is possible to do more delicate and finished work than when water alone is used. It is also possible to paint over a wash or background without disturbing the wash underneath.

3. **Glycerine.**—The colors are ground in glycerine alone, or in fifty parts glycerine and fifty parts water. More glycerine is used when the body is very porous. This medium is probably most useful for general purposes. Either direct painting, flat wash work, or a highly finished technique is possible with glycerine, and it is not necessary to fire the work before glazing.

4. **Turpentine and Fat Oil of Turpentine.**—These two mediums have been in general use both in purely commercial work and by artists specializing in underglaze painting. The colors may be applied quite heavily without danger of peeling or blistering. But it is necessary to fire the ware to a dull red before glazing, in order to burn out the oils.

All the given mediums have been used successfully by highly skilled painters and by decorators working on large-scale production. The choice of medium is simply a question of technique, and suitability to existing conditions at hand.

Hardening on Process

This is the preliminary burning to a dull red heat of the decorated wares before glazing. It is only necessary when the turpentine and fat oil mediums are used, although it may be advisable when much gum arabic is used.

Use of Underglaze White

White is not necessary in work involving white or light-colored bodies, although it is often used effectively either as an opacifer, or in painting lighter colors over darker shades. It is mixed in with the colors as Chinese White is mixed in water colors, and as Flake White in oil colors.

When red or other dark-colored bodies or grounds are required, white is almost an essential, especially when clear light colors are wanted.

Preparation of Surface for Painting

For ordinary purposes little preparation is necessary. It is enough to see that the surface is clean and smooth, and free from grease. A rough biscuit surface can be sand-papered if a very smooth surface is desired. If the surface is too porous, a wash or spray of the same medium used in the painting process may be applied. Many painters rub or brush the painting medium into the bisque surface much as a painter will prepare his canvas. Some painters brush a flux or glaze over the surface. This helps to soften and bind the colors.

Brushes.—The type of brush obviously depends on the technique of the painter, and the class of work under consideration. The only essential is that it be of the best quality. Red or brown sable pointed brushes are suitable for general work in all the mediums. For outlining, ox hair writers are most satisfactory. If large decorative work requiring an oil color technique is to be done, regular oil color bristle brushes are most suitable, but this type of brush can only be used when turpentine and fat oil are the mediums.

Liquid Underglaze Colors

As stated these colors are only suitable for flat decorations. A particular color will give just one value or tone no matter how heavily or frequently the wash is applied unless the ware is subjected to a red heat firing before the second coat is applied. If the ware is soft and porous, the color will spread over the surface. As the nitrates are more or less colorless until they are fired, it is advisable to mark with a lead pencil those surfaces which have been covered. Better results will be obtained if the design is first outlined with a vegetable lamp black using glycerine or fat oil for a medium. This outline will burn away, leaving a white outline. If colored outlines are wanted underglaze colors may be used instead of the vegetable black.

Wares decorated with these liquid colors should be hardened on before they are glazed. The colors oxidize and develop when they are burned to a red heat, and it is possible to make needed corrections before the piece is glazed.

Glazing and Firing

The conditions surrounding these two processes must be very carefully considered. Before any important work is attempted, experiments on medium, glazing and firing should be made. Some colors, the cobalt blues, for instance, develop and are stronger in tone after the ware is fired. Browns, some yellows and greens appear considerably lighter than when applied. The chemical composition of the colors must also be reckoned with. For instance, if an iron-yellow is mixed with a chrome-green the result will not be a yellow-green but a strong brown.

Also, if a tin-white is used with greens containing chrome the result will be pinks and crimsons instead of the lighter and colder greens of the oil color palette. Preliminary trials will determine what mixtures may be safely used. A decoration in underglaze color may have to be painted to appear hard and crude before it is fired to allow for chemical adjustments during the period of firing.

The method of glazing must be considered before the piece is decorated. If the piece is a vase, and water or glycerine is the medium, it will be wise to glaze the inside of the piece before the decoration is applied. This can be done by pouring liquid glaze in the piece and turning it round until the inside surface is covered. The remainder is then poured out.

Unless a flowing effect is desired, only those glazes which do not run should be used. Both matte and glossy glazes may be used providing the applied coat is not so heavy that there will be flow enough to disturb the design. The glazes may be white or colored. If colored, the influence of the glaze on the applied decoration must also be reckoned with. A yellow glaze will change the blues to greens. A manganese glaze will make blue appear purple.

Unless the decoration is on a flat surface, as in tile, care must be taken not to have too heavy a coat of glaze because a slightly too high firing temperature will cause the flowing of the glaze and the running of the colors in the decoration. In making the preliminary trials, the thickness of the glaze coat should be noted, and judgment exercised accordingly when the finished work is being glazed.

Suitable Bodies and Glazes for Underglaze Work

As stated, almost every type of body is suitable for underglaze work. The only condition to bear in mind is that concerned with the use of white in the colors when dark bodies are being decorated. Table III shows white glazes which have been found suitable for underglaze work. If colored glazes are required, the formulas given can be stained in the usual manner, copper for green, uranium or iron for yellow, manganese for brown, cobalt for blue, and combinations of these according to the color desired.

TABLE III

WHITE TRANSPARENT GLAZES

	White Transparent 03–		White Transparent 1–3		White Transparent Cone 8–10
White Lead	330	White Lead	185	Cornwall Stone	240
Feldspar	160	Feldspar	55	Feldspar	240
Flint	175	Flint	35	Flint	225
Whiting	45	Whiting	12	Whiting	150
China Clay	8	China Clay	. . .	China Clay	50
Zinc Oxide	14	Zinc Oxide	10	Zinc Oxide	40
Barium Carbonate	5	Cornwall Stone	55	Barium Carbonate	17
Ground Glass	200			Ground Glass	60
Borax	15			Borax	5
				Tin Oxide	10

Some Historical Types

Of the many kinds of wares decorated with underglaze colors, the blue and white wares are possibly the best known. The Ming, K'ang-hsi, Yung-Cheng and Ch'ien-ling blue and white porcelains are known for their exquisite delicacy and finish, and have been the inspiration for about all the blue and white decorations that have been produced since.

The Persians have used underglaze colors, but generally in connection with colored glazes. In some instances the outline only would be in a crude underglaze color, and the spaces filled in with colored glazes, or a certain part of the decoration would be executed in U. G. colors, and the remainder in colored glazes. The French potters, Deck, and a number of the faience manufacturers have done considerable work in this process. They employed, and now employ painters and decorators of considerable reputation. These artists execute elaborate paintings of figures, landscapes, and exquisitely painted flowers. Some of these works consist of tile panels often ten or twelve feet or more in size.

Mintons of England have perhaps produced a greater variety of underglaze decorations than any other one organization. They had a large force of artists who were specialists in different classes of decorative work, and who painted figures, landscapes, flowers, animals, fish, and conventional decorations on earthenware and porcelain in white and colored bodies.

The Staffordshire printed underglaze decorations are well known, and need little comment.

On the continent, we have the Rozenburg pottery in Holland where rich and highly colored conventional decorations are executed on porcelain, and on a beautiful light terra cotta body. Both tile and ornamental wares are made by this concern. The Copenhagen pottery in Denmark use underglaze processes almost exclusively. The Rorstrand pottery in Sweden also does underglaze work on porcelain of a similar type to that made by the Copenhagen organization.

A large number of individual potters and commercial organizations in Germany are doing underglaze work but to date this process has not been used to a considerable extent in this country, except perhaps in Mexico where decorations showing an Oriental, Spanish and Italian influence are quite common.

It should be hardly necessary to state that there are great commercial and artistic possibilities in the use of underglaze work on the biscuit. Here is a rich and varied palette for the painter who possesses the necessary technique for either oil or water color painting, and in addition it can be used for the mechanical printing processes which, unfortunately, are now almost entirely discarded for the decalcomania decorations. This country possesses many remarkable draftsmen who could design such decorations for printed wares as have not yet been done. We all know how much the Staffordshire printed wares have been sought by collectors after they have enjoyed some thirty years' commercial vogue. It is easily possible that some enterprising manufacturer may commission a draftsman of the reputation and skill of Joseph Pennell or any one of a hundred others to design a series of decorations for utilitarian ware or tile. I think that the commercial and artistic possibilities for the printing process in underglaze colors are so great that it is bound to be revived.

In these references to underglaze decoration, I have not considered the slip or those other processes where underglaze colors are used either on a clay surface or over unfired glazes. These calcinations have many uses other than their connection with painting over a biscuit surface. They are used for both body and glaze stains, and they also form the coloring agent for the slip processes. These, however, will be dealt with in future papers.

Discussion

By Mary G Sheerer:—In addition to what Mr. Rhead has told us in his very interesting paper, I should like to speak of the method of "Preparing the Surface for Painting" in use at the Newcomb Pottery in New Orleans. The body is sponged very thoroughly in the "green" or unfired state to give it the required "tooth" to receive the washes of color after the first-fire, or on the biscuit.

Large flat hair-brushes are used to put on the flat washes with water as a medium. The values are controlled by adding more color with a smaller brush or by removing it with an eraser or stiff brush. It has also been found important to fire the biscuit lightly so it will not only take the washes more readily but that it may be glazed easily by dipping. If the biscuit were fired harder the glaze could not be handled without disturbing the painting or without a "hardening-on" fire.

Gum tragacanth, carefully sifted, is used with the color.

JOURNAL AMERICAN CERAMIC SOCIETY

Preparation of Abstracts

Every article in THIS JOURNAL is to be preceded by an abstract prepared by the author and submitted by him with the manuscript. The abstract is intended to serve as an aid to the reader by furnishing an index and brief summary or preliminary survey of the contents of the article; it should be suitable for reprinting in an abstract journal so as to make a reabstracting of the article unnecessary. The abstract should, therefore, **summarize all new information completely and precisely.** Furthermore, in order to enable a reader to tell at a glance what the article is about and to enable an efficient index of its subject matter to be readily prepared, the abstract should contain **a set of subtitles** which together form a **complete and precise** index of the information contained in the article. This requires at least one and often several subtitles even for a short abstract.

In the preparation of abstracts, authors should be guided by the following rules, which are illustrated by the abstracts in THIS JOURNAL for February and March, 1921.* The **new information** contained in an article should first be determined by a careful analysis; then the subtitles should be formulated; and finally the text should be written and checked.

Rules

1. **Material not new** need not be analyzed or described in detail; a valuable summary of a previous work, however, should be noted with a statement indicating its nature and scope.

2. **The subtitles should together include all the new information;** that is every measurement, observation, method, improvement, suggestion and theory which is presented by the author as new and of value in itself.

3. **Each subtitle should describe the corresponding information so precisely** that the chance of any investigator being misled into thinking the article contains the particular information he desires when it does not, or vice-versa, may be small Such a title as "A note on blue glass," for example, is evidently too indefinite a description of information regarding "Absorption spectra of glass containing various amounts of copper-cobalt and chromium-cobalt." General subtitles, such as "Purpose" and "Results" should not be employed as they do not help to describe the specific information given in the article.

4. **The text should summarize the authors' conclusions and should transcribe numerical results of general interest,** including those that might be looked for in a table of physical and chemical constants, with an indication of the accuracy of each. It should give all the information that anyone, not a specialist in the particular field involved, might care to have in his note book.

5. **The text should be divided into as many paragraphs** as there are distinct subjects concerning which information is given, but no more than necessary. All parts of subtitles may be scattered through the text but the subject of each paragraph, however short, must be indicated at the beginning.

6. **Complete sentences** should be used except in the case of subtitles. The abstract should be made as readable as the necessary brevity will permit.

7. The ms. of all abstracts must be typewritten and double or triple spaced.

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* The rules were prepared by the Research Information Service of the National Research Council. The Society is indebted to Dr. G. S. Fulcher of the Corning Glass Works (formerly with the National Research Council) for the rules and the illustrative abstracts.

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ORIGINAL PAPERS

THE TENSILE STRENGTH OF PORCELAIN[1]

F. H. Riddle and J. S. Laird[2]

ABSTRACT

A method of accurately determining the tensile strength of porcelain has been developed.

The ratio of tensile to compression strength was found to be 5.9 for the special porcelain studied. Triaxial porcelains gave an average ratio of 7.66.

The tensile strength tests show in general a little more variation than compression strength tests.

The tensile strength is of more significance in judging the quality of porcelain than it has been commonly considered.

Introduction

Determinations of the tensile strength of porcelain appear to have been made only rarely, apparently on account of the experimental difficulties involved, and the uncertainty of the results obtained. Friese[3] reports tensile strengths of 1300–2000 kg. per cm. (18,480–28,440 pounds per sq. in.), on the basis of tests made with special test specimens. These results appear very high. Rosenthal and Singer[4] state that the determination of tensile strength is very difficult and report 261 kg. per sq. cm. (3,712 pounds per sq. in.) as the approximate strength of their insulator porcelain.

[1] Contribution from the research laboratories of the Champion Porcelain and Jeffery-Dewitt Insulator Companies.

[2] Received April, 1922.

[3] "Das Porzellan als Isoler und Konstruktions material in der Elektrotechnik," p. 41.

[4] Rosenthal and Singer, *Keram. Rund.*, **29,** 81 (1921).

Watts[1] in a study of electrical porcelain made tensile strength determinations. His specimens were molded by hand in the metal molds used in cement testing and had a cross-section of one square inch. They were broken in a standard cement testing machine, the shoulders of the specimens being cushioned with pasteboard. Only two specimens of each body were tested, so we cannot determine how consistent his results were. He found strengths for cone 10 triaxial porcelains properly vitrified varying from one to three thousand pounds per square inch.

In general, however, the assumption has been made that the strength of porcelain could be determined only by cross-breaking or compression tests. Against the former of these tests may be urged the uncertainty of the modulus of rupture formula as applied to porcelain, and against the latter, the expense of the equipment necessary.

A method of determining the tensile strength of porcelain which appears to give really significant results has recently been reported from this laboratory.[2]

Comparison of the strengths of different porcelain or other clay bodies can be made by this method by means of a small (2000 lb.) inexpensive, tensile test machine, of the type used in testing Portland cement; thus bringing such investigations within the reach of the laboratory of almost any clay-working plant. The results are apparently at least as reliable as those obtained by compression tests, while tests of this type (compression) are possible only when the laboratory is equipped with a testing machine of large capacity, 50,000 to 100,000-lb. capacity at least; and so are out of the question for most clay-working plants.

Apparatus Used

Two types of test specimens have been devised, designed to eliminate as far as possible transverse stresses and excessive local stresses which would tend to produce shattering. Either of these specimens, having a minimum cross-section of 0.125–0.2 sq. in., may be broken in an ordinary 2000-lb. Olsen cement testing machine provided with special grips (Fig. 1).

Test specimen No. 1, Fig. 2, has conical ends or shoulders which make an angle of about 15° with the straight portion in the center (see Fig. 2). The test specimen T is held by small steel clamps consisting of the split bushing B ground to fit the fired specimen and held by the collar C, the load being applied through the ball and socket joint by means of the plate P_1 held in slots in the jaws of the testing machine. A soft gasket G of blotting paper is inserted between the porcelain and the bushing to distribute the load, or else the porcelain will fail with a small load by splitting into thin

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[1] Watts, *Trans. Am. Ceram. Soc.*, **4**, 86–130 (1902).

[2] Riddle and Laird, *Proc. A. S. T. M.*, **21**, 1050–56 (1921).

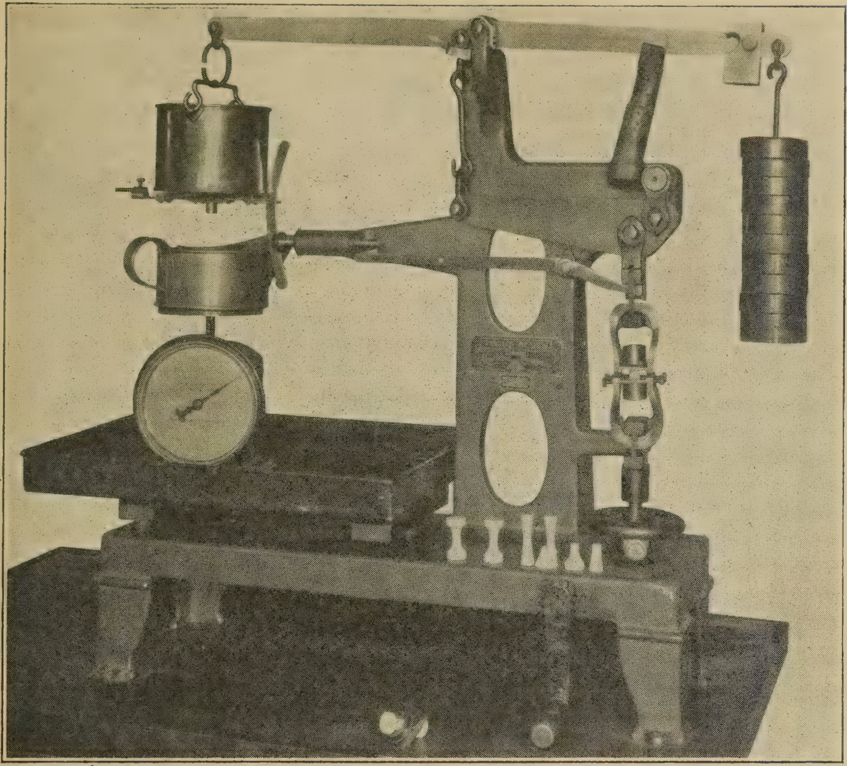

FIG. 1.
Testing machine used with 0.4–0.5-in. test pieces.

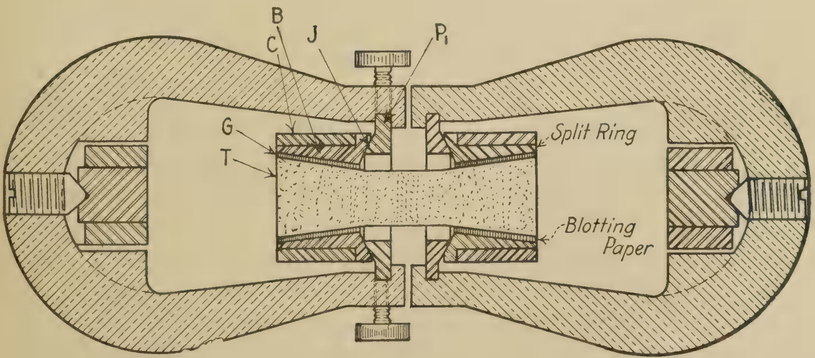

FIG. 2.

disks. A fresh gasket is used with each specimen. Specimens of this type may be used either glazed or unglazed, but must be of uniform size and shape or they will not fit the clamps.

Test specimen No. 2 (Fig. 3) is dumb-bell shaped, the diameter of the ends being about twice that of the reduced central portion (see Fig. 3). In testing, it is held by a split ring R with the same radius of curvature as the shoulders of the specimen. This ring fits into a recess in the plate P-2, which in turn is held in the slots in the jaws of the testing machine. No gasket is required with this piece if the shoulders are glazed, but satisfactory results have not been obtained with unglazed pieces even by using a gasket.

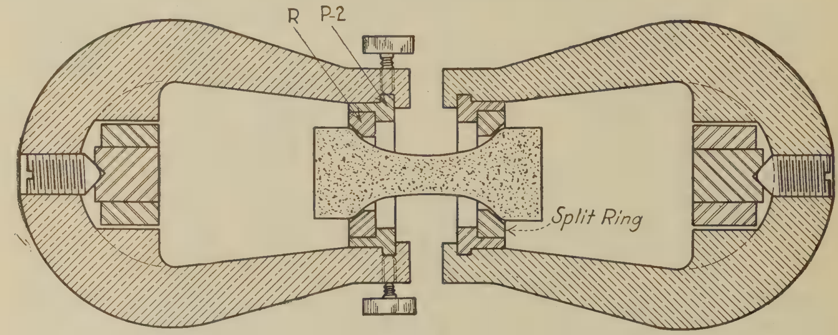

FIG. 3.

Of the two types, No. 1 appears to give slightly higher results; possibly on account of its shape it stands firing better. The second type requiring no gasket permits of more rapid manipulation, and is more satisfactory when there is any considerable variation in size or the pieces have warped in firing.

Preparation

Test specimens have been prepared by pugging and extruding rolls of suitable size, throwing rolls by hand, and by cutting blanks from large pugged and cast blocks. It has been found that different strengths are shown by specimens prepared in different ways, and for comparative tests there must be strict adherence to one standard method of preparing the blanks. The blanks are turned in the green condition to such dimensions as will give fired specimens of standard size, shrinkage being determined and allowed for as in regular ceramic practice. The minimum cross-section of the fired specimen is determined by calipering and averaging a number, the variation from standard dimensions being kept within very narrow limits as it has been found that with specimens of about 0.2 sq. in. the calculated tensile strength increased about 0.5 per cent for a decrease in an area of 1 per cent.

When dry, the shoulders of the specimens are glazed, the central portion of minimum cross-section being left free from glaze to avoid the effect of the glaze in increasing or decreasing the strength of the specimens. This glazing of the shoulders is necessary with specimens of the second type, and is employed with those of the first type for the sake of uniformity and to insure that failure occurs in testing in the central cross-section of the specimen.

The glazed test pieces are fired on end in sagger usually on a little placing sand or in clay bats. Completely covering the specimens with sand causes them to break in firing. The specimens are burned in the regular porcelain kilns (or where noted in special experimental kilns). Specimens which warp in firing give unreliable results and should be rejected.

Results Obtained

A large number of tests have been made with porcelain specimens prepared and tested as described above. The consistency shown by the results indicated that this method gives an accurate measurement of the relative strengths of different porcelains, agreeing with the results shown in using the porcelain on a commercial scale.

In a series of tests the average variation of a single determination from the mean of the series is 14 to 15 per cent, the maximum variation, 30 to 40 per cent. It is therefore necessary to test 15 to 20 specimens to obtain a value reliable to a few per cent. This refers to porcelain which has been satisfactorily prepared and fired. Specimens which have been subjected to considerable variation in heat treatment, or have been subject to strains in forming so that they warp on firing are much less uniform.

TABLE I

TENSILE PROPERTIES OF PORCELAIN

Test specimen	Aver. cross-section area, sq. in.	Aver. load, lbs.	Aver. strength, lbs. per sq. in.	Variation per cent Aver.	Variation per cent Max.
	TRIAXIAL PORCELAIN				
No. 1 (conical)	0.131	816	6249	15.0	39.7
No. 2 (dumb-bell)	0.127	731	5760	15.6	23.2
	SPECIAL PORCELAIN				
No. 1 (conical)	0.129	1320	10250	17.7	37.9
No. 2 (dumb-bell)	0.130	1211	9390	15.1	33.9

Table I gives the results of a typical series of tests, the specimen blanks being formed by pugging. About twenty specimens were tested in each case.

On the basis of the tests which have been made by this method we have determined that good triaxial porcelain has a strength of 3000 to 6000 lbs. per sq. in., calculated from the breaking strength of specimens of 0.4 in. in diameter. Special high temperature porcelains show strengths running up to 10,000 to 12,000 lbs. per sq. in.

Comparison with Compression Tests

Compression test specimens were prepared by pugging rolls of special porcelain body with a diameter of one inch (after firing). After drying these were cut to give a fired length of about 2.5 inches on a specially designed wheel so that the two ends were truly parallel and as nearly as possible at right angles to the axis of the cylinder. A number of these specimens were fired in the same sagger with a number of tensile test specimens prepared from the same porcelain body. Four separate lots were fired and tested.

They were crushed on a large Olsen testing machine of 100,000 pounds capacity. In some cases the specimens were in direct contact with the iron compression plates of the machine. In other cases thin sheet lead was inserted between the porcelain and the iron to eliminate inequalities. The latter method gave results which were a little more uniform, but a little lower on the average. Failure under test with these specimens was a little peculiar, as in most cases there first occurred a splitting of the specimens into longitudinal segments. Then the load could sometimes, particularly when using the lead cushions, be increased considerably before complete failure occurred by crushing into many small fragments. About twelve specimens were tested in each experiment, and the results given are averages of all the specimens tested.

Table II

Experiment		Area, sq. in.	Load, lbs.	Strength, lbs. per sq. in.	Variation, per cent	Ratio
1.	Tension	0.134	1,251	9,292	16.4	1:5.74
	Compression	0.760	40,071	53,355	13.1	
2.	Tension	0.135	1,244	9,194	21.8	1:6.27
	Compression	0.760	43,899	57,720	16.3	
3.	Tension	0.135	1,454	10,749	11.1	1:5.79
	Compression	0.760	47,405	62,335	12.1	
4.	Tension	0.133	1,285	9,639	23.9	1:5.92
	Compression	0.760	43,410	57,080	12.4	
				Average Ratio		1:5.90

The variation in strength of the tensile test specimens is in general a little greater than that of the compression test specimens. The ratios between tensile and compression strengths show quite satisfactory agreement.

The ratio between tensile and compression strengths is undoubtedly affected by variations in the preparation of the specimens and possibly varies with changes in the composition of the porcelain. As determined for twenty-two triaxial porcelains it averaged 7.66, as compared with 5.90, the average results obtained with special high-fire porcelain.

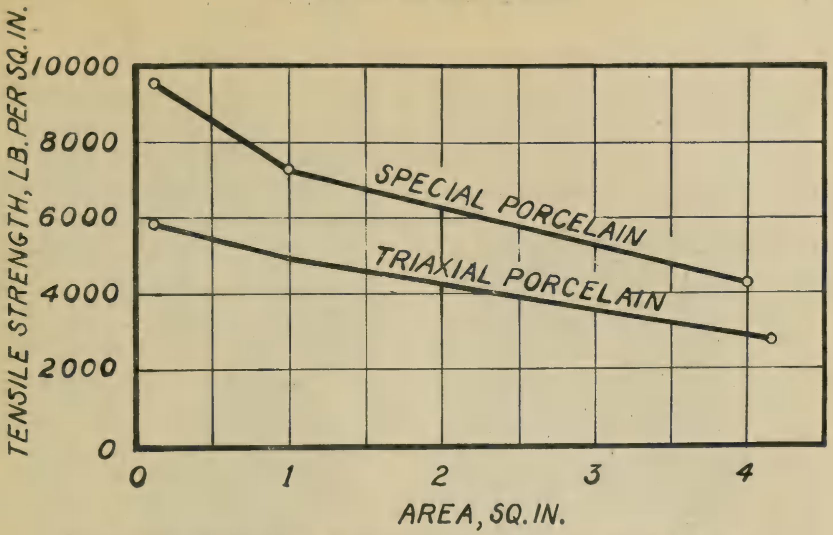

FIG. 4.—Relation between tensile strength and cross-section of porcelain.

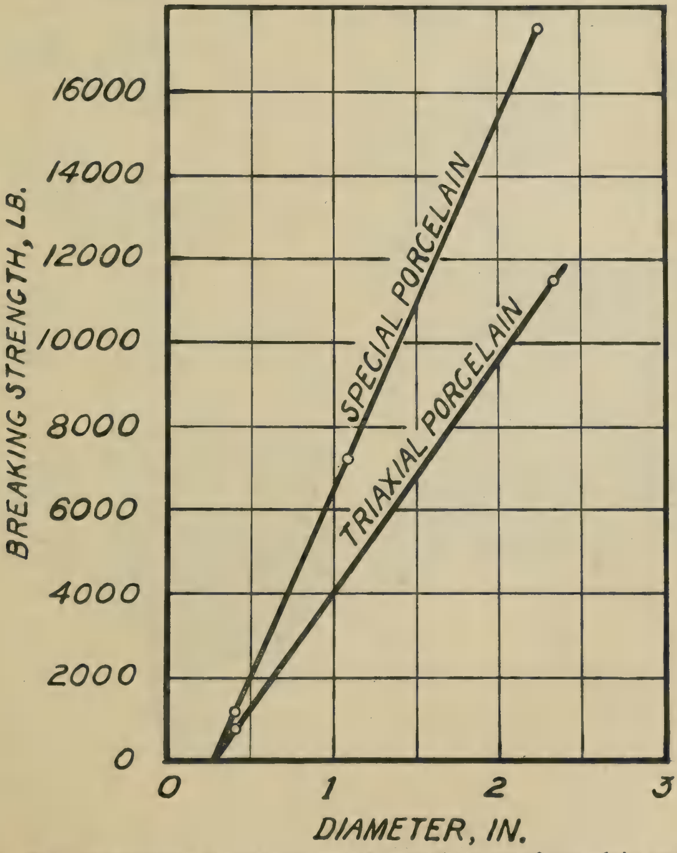

FIG. 5.—Relation between breaking strength and diameter of porcelain test specimen.

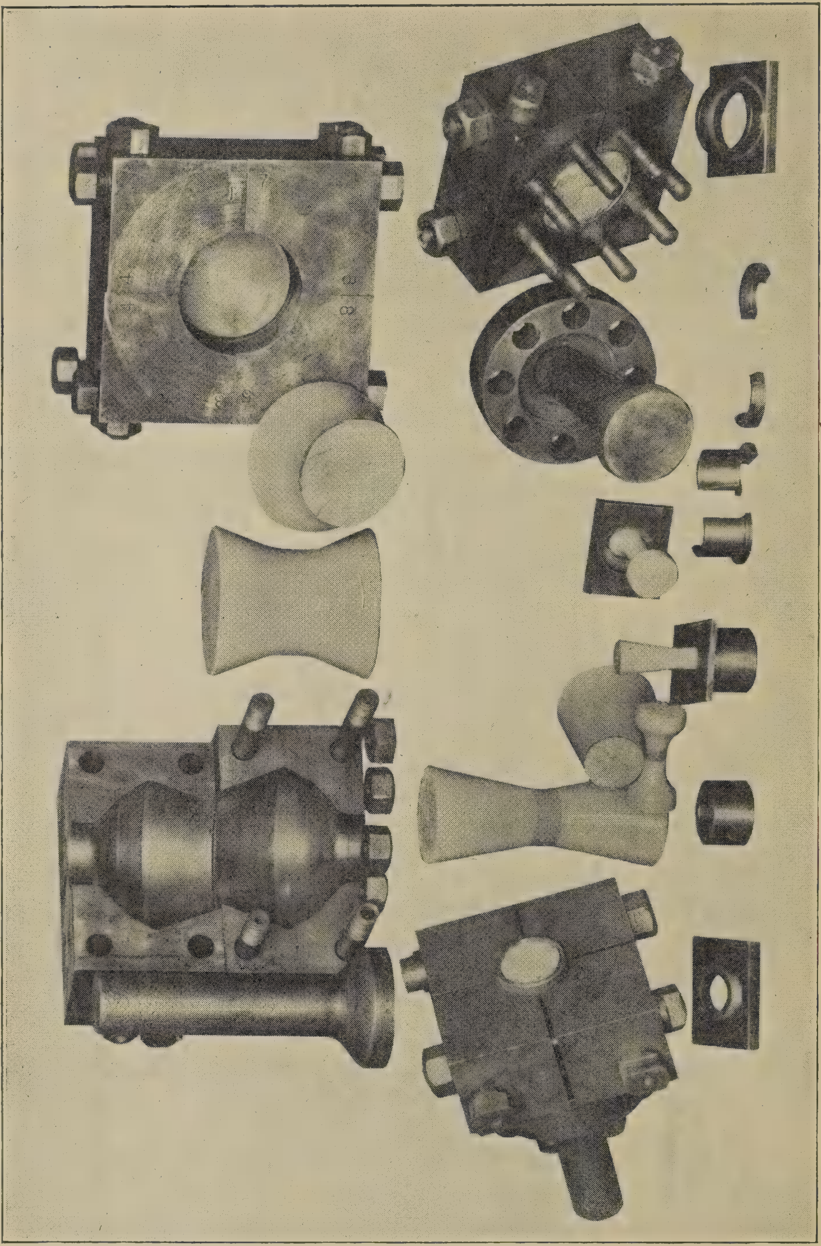

Fig. 6.—Test specimens of different sizes and grips used in breaking them.

Unfortunately in the case of the triaxial porcelains the tensile and compression test specimens were not fired together. It should also be noted that in these compression tests, which were made at the Bureau of Standards, the ends of the compression test specimens were ground and polished after firing. This may have given higher results than were obtained with our specimens which were ground but not polished.

It should also be noted that these ratios are dependent on the size of test specimen. The calculated tensile strength, decreases markedly with increase in cross-section of the test specimen. As reported in the article mentioned, tests with specimens of 0.4″, 1.125″ and 2.25″ diameters showed an increase of breaking strength almost proportional to the increase in diameter instead of to the increase in area. This relation is expressed approximately by the equation: $S = (d - {}^1/_4) \frac{S_2}{d_2 - {}^1/_4}$; where S = *strength of specimen*, d = *diameter of specimen*, S_2 = *strength of small specimen*, d_2 = *diameter of small specimen*. This is shown in the accompanying diagrams (Figs. 4 and 5). Fig. 6 illustrates grips and different sized specimens.

From a practical point of view the results obtained by means of this tensile strength test have been found to be very significant not only in cases when the porcelain is loaded in tension, but also when it must resist impact shock. In the case of impact resistance particularly, the tensile strength seems to give a more reliable indication of the value of the porcelain than the compression strength.

A SIMPLIFIED METHOD OF DETERMINING THE DRY VOLUME OF CLAY BRIQUETTES

By J. L. Crawford[1]

ABSTRACT

The dry volumes of clay briquettes for use in a draw trial burn are determined by dividing the dry weight by the bulk specific gravity. This method eliminates saturation of the test pieces with kerosene.

In testing a number of clays, the writer experienced considerable difficulty in determining the burning shrinkage when the standard method of the American Ceramic Society and of the American Society for Testing Materials was used. This method involves the saturation of the dry briquettes with oil and necessitates considerable weighing when a large volume of work is being done. It is often extremely difficult to remove the last traces of kerosene and when this is not done the briquettes break or crack upon being heated. Consequently, the results obtained by this method show numerous irregularities. In view of these results, several modifications were applied in order to eliminate the oil saturation and lessen the number of weighings.

The following method of procedure was finally developed. Four or five extra briquettes are made, weighed dry, and saturated with kerosene. Their volumes are determined in the usual way and the bulk specific gravities[2] determined by formulas 1 or 2.

$$\text{Bulk sp. gr.} = \frac{\text{Dry weight}}{\text{Volume}} \quad \text{(by volumeter)} \tag{1}$$

$$\text{Bulk sp. gr.} = \frac{\text{Dry weight} \times \text{S. G. kerosene}}{\text{Saturated wt.} - \text{suspended wt.}} \quad \text{(by weighing method)} \tag{2}$$

The remainder of the test pieces are simply weighed dry and their volumes are determined by means of formula 3.

$$\text{Volume} = \frac{\text{Dry weight}}{\text{Bulk specific gravity}} \tag{3}$$

When this method was applied to several clays and mixes the maximum variation of the bulk specific gravity from the mean was found to be .005,

Table I

Material	Grog and plastic clay A	Plastic fire clay B	Brick clay C	Flint clay D	Washed pot clay E
1	1.960	1.525	2.000	1.860	1.875
2	1.960	1.525	2.010	1.860	1.870
3	1.970	1.525	2.010	1.850	1.875
4	1.960	1.520	2.000	1.860	1.870

---

[1] Industrial Fellow of the Mellon Institute of Industrial Research, University of Pittsburgh, Pittsburgh, Pa.

[2] The bulk specific gravity is defined as the specific gravity of the composite piece.

with a balance accurate to .05 grams. The results in Table 1 are typical for the specific gravity check determination.

Data that give a direct comparison between this method and the standard method are also available. Twenty briquettes (F) were made from plastic clay and twenty were made containing 50 per cent of grog (G). The volume of each briquette was determined by each method. The results of this comparison are given in Table II and demonstrate that the modified procedure is equally as accurate as the standard.

Subsequent application of the modified method further demonstrated that the volume change curves were smoother and freer from erratic results. This fact is undoubtedly due to two causes, the decreased handling of each test briquette, and the omission of the oil saturation. When the latter does not actually cause cracking or breaking it undoubtedly causes flaking to a smaller degree.

TABLE II

		F			G	
	Measured[1] vol., cc.	computed[2] vol., cc.	Bulk sp. gr.	Measured vol., cc.	computed vol., cc.	Bulk sp. gr.
1	21.80[3]	21.80	1.785[4]	20.55	20.55	1.965
2	20.30	20.30	1.780	23.50	23.45	1.960
3	19.30	19.30	1.785	24.75	24.80	1.970
4	21.50	21.55	1.790	22.50	22.55	1.965
5	18.65	18.60	1.785	22.05	22.05	1.960
6	18.25	18.25	1.785	23.70	23.75	1.970
7	21.50	21.55	1.790	23.90	23.90	1.965
8	18.90	18.90	1.790	25.85	25.80	1.960
9	18.80	18.75	1.780	22.95	23.00	1.970
10	19.75	19.80	1.790	23.80	23.85	1.965
11	19.25	19.25	1.780	22.85	22.85	1.965
12	24.05	24.05	1.785	20.75	20.80	1.970
13	19.60	19.65	1.785	26.95	27.00	1.970
14	19.25	19.25	1.785	23.65	23.70	1.970
15	19.80	19.75	1.780	24.05	24.05	1.970
16	20.05	20.05	1.785	25.90	25.90	1.970
17	20.75	20.75	1.785	22.65	22.70	1.960
18	20.10	20.10	1.785	22.00	22.00	1.965
19	18.50	18.55	1.780	24.75	24.75	1.970
20	18.65	18.60	1.785	22.05	22.05	1.965
Average			1.785			1.965

[1] Determined by old method—saturated weight minus suspended weight.

[2] Determined by new method—dry weight divided by bulk sp. gr.

[3] The volumes are computed to the nearest 0.05 cc.

[4] The bulk specific gravities are computed to the nearest 0.005.

It is, therefore, unnecessary to saturate any of the briquettes used in a draw trial burn with kerosene. It is only necessary to saturate a few briquettes which were made under the same conditions in order to determine the average bulk specific gravity of all the briquettes. The volumes of those to be fired may be calculated from their dry weights and bulk specific gravities. This modified method lessens the number of weighings and eliminates oil saturation of the pieces to be burned. This results in a saving in time spent in weighing. It also results in eliminating the difficult task of drying the oil saturated pieces, in preventing cracking in the furnace, and in giving a smoother burning curve.

In conclusion, the writer maintains that in determining the volume burning shrinkage of a clay it is quicker, simpler and more accurate to calculate the dry volume of the briquettes from the dry weight and bulk specific gravity as explained above than to saturate each briquette in kerosene.

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Pittsburgh, Pa.

Discussions

By E. W. Washburn:—The simplest and most convenient, as well as the most rapid and most accurate, method of determining the dry volumes of clay briquettes is by the use of a properly constructed mercury volumeter. For example, with the rapid porosimeter (*Jour. Am. Ceram. Soc.*, **5**, 125, Fig. 11) a determination of the bulk volume of a briquette to an accuracy of 0.02 cc. can be made in 2 minutes. No weighing is required. A somewhat more accurate result (*ca.* 0.005 cc.) can by obtained by using a volumeter of the type shown in Figs. 9 and 10 (*l. c.*) and weighing the mercury withdrawn.

By E. N. Bunting:—Mr. Crawford's procedure is an improvement upon the standard method when several determinations are made. However, it is not necessary to use oil to determine the bulk sp. gr., as the volume can be determined accurately and rapidly in a mercury volumeter of correct design. Briquettes of the same batch seldom differ in bulk sp. gr. by more than $^1/_2$%, so the author's assumption that the bulk sp. gr. of any one briquette can be determined from the average bulk sp. gr. of a few is fairly correct.

By H. H. Sortwell:—The method of determining volumes described by Mr. Crawford is an excellent one from the standpoint of saving time, minimizing routine work, and eliminating the difficulty of safely removing the kerosene from the trial pieces. During the past year in a study of ball clays, a preliminary report of which appeared in *The Ceramist*[1] it was found to be practically impossible to completely remove the kerosene from some of the very plastic English ball clays in any reasonable length of time without damaging the pieces. In order to determine the volumes without saturating the pieces with kerosene a similar method was used in combination with the Schurecht pycnometer. In the writer's judgment Mr. Crawford has presented enough data to show that this method is sufficiently accurate for all practical testing.

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[1] "The Properties of Some Ball Clays," H. H. Sortwell, *The Ceramist*, **2**, 5 (1922).

FIRE CLAYS OF THE EASTERN COALFIELD OF KENTUCKY[1]

By H. Ries[2]

ABSTRACT

The eastern coalfield of Kentucky contains two horizons of workable refractory clays. One of these bearing flint, semi-flint and plastic clay is definitely proven to be of upper Pottsville age, and rests unconformably on the Mississippian formations. The other found in Boyd and eastern Carter County is in the Allegheny series and carries plastic fire clay of less commercial value. A number of points, not hitherto emphasized or noted are described.

The fire clay deposits of the eastern coalfield of Kentucky have long been known, and serve as the basis of a flourishing refractory product industry. They have, moreover, been discussed from time to time by different writers,[3] so that it might seem superfluous to devote any more space to them, and the main reason for doing so is for the purpose of bringing out certain facts, not hitherto mentioned, and others regarding which there may be a difference of opinion with previous investigators.

Formations of the Eastern Coalfield

The bed rock formations occurring in that part of Kentucky lying roughly east of a line drawn from opposite Portsmouth, Ohio, through Irvine and Somerset, Kentucky, range from Silurian to Pennsylvanian in age. The pre-Pennsylvanian formations contain, so far as known, no clays of refractory character, and consequently it is only the Pennsylvanian strata that concern us.

The formations of the last-named system of rocks, which underlie the greater part of the area under discussion, are represented by the Pottsville, Allegheny, and Conemaugh series, named in ascending order. Of these, only the Pottsville and Allegheny have so far yielded refractory clays.

Pottsville Clays.—At the bottom of the Pottsville series as exposed in Carter, Boyd, Elliott and Rowan Counties there is found an extensive, but not continuous, deposit of fire clay, which has assumed great industrial importance, and which is often referred to as the Olive Hill fire clay, because of the locality in Carter County, where it was first developed.

Character of the Olive Hill Fire Clay.—This fire clay deposit is made up of three different grades known as: (1) Flint, (2) Semi-hard, soft-hard or semi-flint, and (3) No. 2 plastic.

The flint clay is very fine grained, has a conchoidal fracture, and in color is often buff or gray, but sometimes dark gray, black, or even red. It occasionally grades into a sandy phase, which contains minute grains of quartz.

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[1] Published by permission, State Geologist of Kentucky.

[2] Refractories Division, St. Louis Meeting, Feb. 28, 1922.

[3] A. F. Crider, *Ky. Geol. Surv.*, 4th Ser., **1**, II (1913); S. L. Galpin, *Trans. Am. Ceram. Soc.*, **14**, 301 (1912); A. F. Greaves-Walker, *Ibid.*, **9**, 461 (1907).

At a few localities an oölitic variety of flint clay is found, which contains small oölites imbedded in a matrix of normal flint clay. This variety was described by Greaves-Walker[1] as occurring in the Burnt House mine (now abandoned) at Olive Hill and he proposed the name of *Aluminite* for it. A peculiarity was its high percentage of alumina, which is due as shown by Galpin,[2] to the fact that the oölites are composed of gibbsite (Al_2O_3, $3H_2O$). This type is not found in any of the other mines around Olive Hill, but Crider[3] has noted its occurrence at several other localities.

While the flint clay shows high refractoriness, the deposits may occasionally show impurities such as pyrite concretions, and films of gypsum, the latter occurring in the irregular cracks that traverse the flint clay in all directions, but not in sufficient quantity to reduce its refractoriness. Quartz grains are present where the flint clay grades into sandstone.

A microscopic study of the flint clay by Galpin[4] shows that the flint clay contains kaolinite, hydromica, pyrite, quartz, rutile, zircon, and tourmaline, but all except the first two, only in small amounts. Gibbsite was found only in the oölitic clay.

The semi-hard clay differs from the flint in being slightly softer, in having noticeable plasticity, and in showing the presence of numerous slickensided surfaces which commonly traverse the flint clay in all directions, although occasionally they follow a prevailing one.

It is usually quite sharply separated from the flint clay, but like the latter may contain pyrite concretions and gypsum films. In some mines it shows minute white specks about $^1/_{32}$ inch diameter, which may be gypsum. Hydromica is more abundant than kaolinite.

The No. 2 plastic clay, differs from the other two in having decided plasticity. It is softer than the semi-hard, but shows an abundance of slickensides, and is the least refractory of the three. In some cases it can be used for a lower grade of fire brick.

Relations of the Three Fire Clays.—Some of the previously published sections may lead one to infer that the three clays above mentioned occur in rather regular beds within the deposits, but a careful comparison of the sections studied in different mines brings out the fact that there is no definite order of deposition. It is true that a definite relationship may hold throughout one mine, but it does not hold in all parts of the area in which these clays occur. In some mines practically nothing but flint clay may occur, in others only semi-hard, but none was seen where No. 2 plastic alone is found. It is not common however to find any one variety forming the entire deposit in any one mine.

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[1] *Trans. Am. Ceram. Soc.*, **9**, 461 (1907).

[2] *Ibid.*, **14**, 301 (1912).

[3] *Ky. Geol. Surv.*, 4th Ser., **1**, II, 589 (1913).

[4] *Loc. cit.*

Extent of Fire Clay Deposits

The three associated fire clays just described are found throughout a wide area of territory extending from the Ohio River on the northeast, to Elliott County on the southwest, although the deposit is not a continuous one, for the clays are wanting in spots due either to non-deposition or erosion.

The former condition is indicated by the fact that the fire clay at places grades laterally into a sandstone and the latter condition by the occasional close but unconformable contact between the Pottsville conglomerate and the lower lying Waverly beds of the Mississippian system. Along the line of the Chesapeake and Ohio Railway they are found from Aden on the east to Morehead on the west.

FIG. 1 —Entrance to mine of Ashland Fire Brick Co., Hayward, Carter Co., Ky.

Roughly speaking the area within which the fire clay deposits have been found outcropping is about 660 square miles.

Within this area the development has been chiefly in a zone bordering the Chesapeake and Ohio Railway, but some companies have built narrow gauge railroads to mines 4 or 5 miles distant from the main rail line.

Much drilling has, however, been done in practically all parts of the area, and reserve supplies blocked out, so the several fire brick companies either own extensive undeveloped clay lands, or control the mineral rights on them. There is, no doubt, a large reserve tonnage in the district as a whole but it is impossible to state exactly how many years it will last, although there is no danger of early exhaustion. To the east of Aden the fire clay passes below the surface since the strata dip in that direction, and that it probably continues with depth is shown by the fact that about one mile east of Denton, Boyd County, it was struck at a depth of 625 feet below the surface.

The thickness of the fire clay as determined from a study of the beds and drill records ranges from almost zero to 29 feet, the larger figure representing a bed of solid flint clay said to have been struck in boring.

Relation of Fire Clay to Underlying Formations

At most localities where the fire clay occurs the Maxville limestone is found below, but not always in actual contact with it. Erosion which preceded the deposition of the fire clay, has cut the limestone to a variable degree in different places, and in cases has removed it completely as at Iron Hill, Carter County, where, according to Crider,[1] the flint clay rests directly on Waverly sandstones and shales.

Only rarely does the fire clay rest directly on the limestone, being usually separated from it by a red mottled plastic clay known as "pinkeye," by sandstone or by shale. Crider has stated that the pinkeye is calcareous and furthermore that it is a residual deposit derived from the Maxville limestone. So far as my observations go, I have not observed any pinkeye that is calcareous, nor should one expect it to be if it is residual, as weathering usually leaches the lime carbonate out of a rock. Nor can I agree with him that it represents a residual deposit from the Maxville limestone, because sometimes there is sandstone between the two.

As a rule the pinkeye is of low refractoriness, but occasionally it is sufficiently refractory to be used in fire brick.

Immediately on top of the limestone there is sometimes a cherty mass that appears to have been altered by weathering, and which may be from 1 to 3 feet thick. A good section of this is seen in the mine of the Ironton Fire Brick Company near Enterprise, Carter County.

The interval between the bottom of the fire clay and the top of the Maxville limestone is exceedingly variable. Data obtained from sections at mines and from drill records which I was kindly permitted to examine show that this interval ranged from one foot eight inches to 25 feet. One section showed 22 feet of shale between the fire clay and the limestone, in another there was sandstone between the pinkeye and fire clay, while in still other cases the floor of the fire clay was pinkeye in one place and sandstone in another, even within the same mine.

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[1] *Loc. cit.*

There is no doubt that the fire clay is separated from the Maxville limestone by an unconformity, and this break may be above the shale and sandstone sometimes found overlying the lime rock. That this unconformity represents not only uneven erosion, but also considerable erosion in places, is shown by the variable thickness of the limestone which ranges from 0 to 100 feet, the former figure being represented by one drill hole in which the fire clay was found resting on the Chester sandstone (Crider).

It is probable that some of the soft sandstone associated with and grading into the fire clay, as well as the pinkeye clay, are above the unconformity.

Relation of Fire Clay to Overlying Formations

The rock immediately overlying the fire clay may be shale, sandstone, coal, coarse conglomerate, or Pottsville pebbly sandstone.

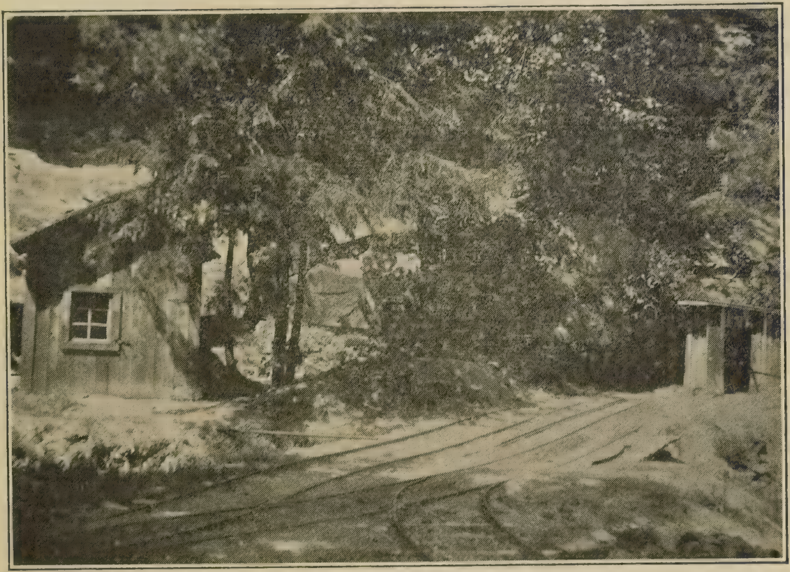

FIG. 2.—Entrance to mine of Louisville Fire Brick Works, Grahn, Carter Co., Ky. Shows Pottsville pebbly sandstone roof, over fire clay.

While the coal is usually above the fire clay, and often rests directly on it, there are times when it occurs within the fire clay near its upper limit. It may be entirely absent, and in any event is rarely over six inches thick.

The shale when present is conformable with the clay, and is sometimes quite carbonaceous. It may also contain concretions of siderite and pyrite.

At Hayward, for example, there is between the shale and fire clay a hard, fine grained sandstone, known as "whim rock," which contains small angular particles of flint clay.

At Grahn, the Pottsville pebbly sandstone rests directly on the fire clay in places, but in one mine there are found flat lenses of a coarse conglomerate, consisting of pebbles up to an inch in diameter, in a matrix of quartz sand and mica scales. The pebbles are mostly quartz, but where the black shale lies between the fire clay and conglomerate, some of the pebbles are of shale and of siderite.

Here then there is an unconformity between the Pottsville pebbly sandstone and the fire clay and black shale. A similar unconformity has been noted in some other mines.

The thickness of the Pottsville pebbly sandstone above the clay is variable, and the range shown by a number of drill records is from 50 to 130 feet.

In this Pottsville sandstone above the fire clay, there may be one or several beds of a mottled clay known as "Huckleberry clay" which is said to be non-refractory. The thickness of these as encountered in different drill holes ranged from 2 to 15 feet, and the interval between the fire clay and the nearest bed of Huckleberry ranged from 2 to 35 feet.

In two holes where no fire clay was present there was 20 feet of sandstone between the Huckleberry and limestone in one case, and 39 feet of shales and sandstones in another case. In short, the Huckleberry does not appear to occupy any definite position in the section above the clay.

Age of the Olive Hill Fire Clays

While there has been much discussion regarding the geologic age of the flint and associated fire clays of the Olive Hill region, most writers have placed it in the Pottsville series of the Pennsylvanian, rather than in the Mississippian.

Most observers agree that the fire clay formation lies above the Maxville limestone of the Chester, a subdivision of the Mississippian, and that it is separated from the lime rock by an unconformity. Moreover, the clay miner and prospector look for the clay above the limestone.

This position of the clay above the limestone, and the unconformity has no doubt caused the majority of observers to place it in the Pottsville.

Miller[1] has however called attention to an occurrence of flint-like clay near Blairs Mill, Rowan County, which is overlain by Mississippian limestone, and has suggested, that this indicates that the clay is of the above-named age.

While there seems to be no doubt regarding the age of the "flint clay"

[1] *Dept. Geol. and For., Ky.*, Ser. V., *Bull.* **2**, 330 (1919).

which he refers to, the other evidence indicates that the Olive Hill flint clay is not of Mississippian age, because; (1) the so-called flint clay at Blairs Mill is not such, but is a clay of low refractoriness, (2) no limestone has been found above the fire clay in the hundreds of drill holes that have been put down in Greenup, Carter, Rowan and Elliott counties.

This it would seem rules out the theory that the clay is of Mississippian age. Further evidence is afforded by plant remains found immediately above the fire clay, and below the unconformity between it and the Pottsville sandstone, for these plants have been definitely identified by Dr. David White as of upper Pottsville age.

It would appear then that following the deposition of the Maxville limestone, and some shale and sandstone, there was a period of erosion which in places removed much or all of the lime rock. On this undulating surface there were deposited the pinkeye clay, semi-plastic fire clay and flint clay, the No. 2 plastic, and the thin seams of coal and carbonaceous shale. In places some thin deposits of iron ore also accumulated. There followed then another interval of erosion before the Pottsville conglomerate was deposited.

The Fire Clay of Allegheny Series

The Allegheny series of the Pennsylvanian contains a deposit of plastic fire clay associated with the Vanport or ferriferous limestone in parts of Carter and Boyd Counties.

In Boyd County[1] it usually lies 10 to 40 feet above the top of the Homewood (Pottsville) sandstone, and between coals Nos. 5 (Brookville) and 6 (Lower Kittanning). If coal No. 5 is absent the clay may lie even nearer the Homewood sandstone.

The fire clay outcrops in the hills both southeast and northwest of Ashland, and north of Catlettsburg.

The dip of the formations causes it to disappear near the mouth of the Big Sandy River, and it does not reappear north of Louisa in Lawrence County on the south. From Louisa it outcrops in the hills in the form of a great arc, following the outer edge of the basin, and coming back to the Ohio River at Ashland.

In Carter County the clay comes up with the dip and is seen above the C. & O. Ry. tracks about one mile east of Denton.

Near Hitchins the clay is found near the tops of the ridges and is not to be looked for any farther to the west.

The plastic fire clay while associated with the Vanport limestone, is sometimes above and sometimes below it. Indeed at some of the mines in Carter County no limestone is found with the fire clay, moreover even in the same mine the thickness of the limestone may vary.

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[1] W. C. Phalen, *U. S. Geol. Surv., Bull.* **349**, 1918.

It has also been noticed in working the clay that it occasionally grades into material of lower refractoriness and more ferruginous character, necessitating abandonment of the entry or sometimes the mine.

It seems probable that at the horizon of the Vanport limestone there is a clay deposit of variable, and sometimes appreciable thickness, and that certain beds or lenses in this deposit may be of refractory character, but that these refractory beds do not all occupy the same position in the clay member, nor are they always of great extent.

The Vanport fire clay is usually plastic, but these are occasionally pockets of flint clay found in the plastic material.

The plastic clay is usually, mottled gray and yellow, and occasionally shows concretions of pyrite and thin films of gypsum. The thickness in different mines ranges from 3 to 10 feet, the floor being often a micaceous sandy clay.

Owing to the fact that the Allegheny plastic fire clay is not as refractory as the Pottsville flint and semi-hard clays it is less in demand, and when worked it is for the purpose of mixing with the more refractory clays found to the westward.

In the summer of 1921 the only mines in steady operation were those of the Ashland Fire Brick Company, northwest of Ashland, the Harbison-Walker Refractories Company, 2 miles south of Denton, and the General Refractories Company at Hitchins.

The section at the mine south of Denton showed:

Impure clay shales	50 ft.
Plastic fire clay	4½ ft.
Sandy micaceous clay	——

These clays average from cones 30–31 in their refractoriness. Some drop as low as cone 29 while others have tested as high as cone 33.

The Fire Brick Industry

With the development of the fire clays of eastern Kentucky, there has gradually developed a thriving fire brick manufacturing industry, which is supported mainly by the Pottsville refractory clays, the plastic fire clays of the Allegheny series being drawn upon to a lesser extent. Most of the plants are located in eastern Kentucky, but one is at Louisville and in addition the clay is shipped to factories in Ohio and Pennsylvania.

According to Crider,[1] S. Eifort, K. B. Grahn and J. McL. Stoughton purchased a large tract of land in the Olive Hill district about 1868, with the intention of erecting an iron furnace. As there was no railroad through the district then, the venture was unsuccessful.

[1] *Loc. cit.*

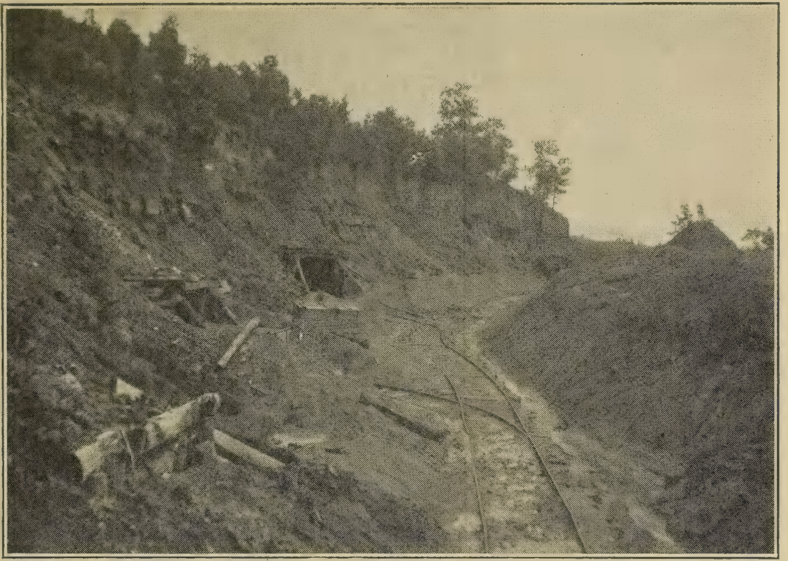

FIG. 3.—Plastic fire clay pit of General Refractories Co., Hitchins, Carter Co., Ky.

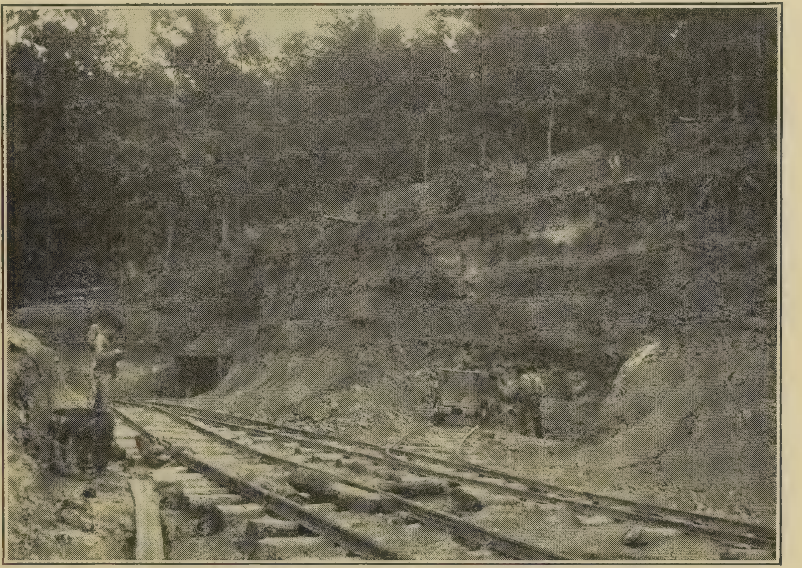

FIG. 4.—Plastic fire clay mine of Harbison-Walker Refractories Co., 2 miles south of Denton, Boyd Co., Ky.

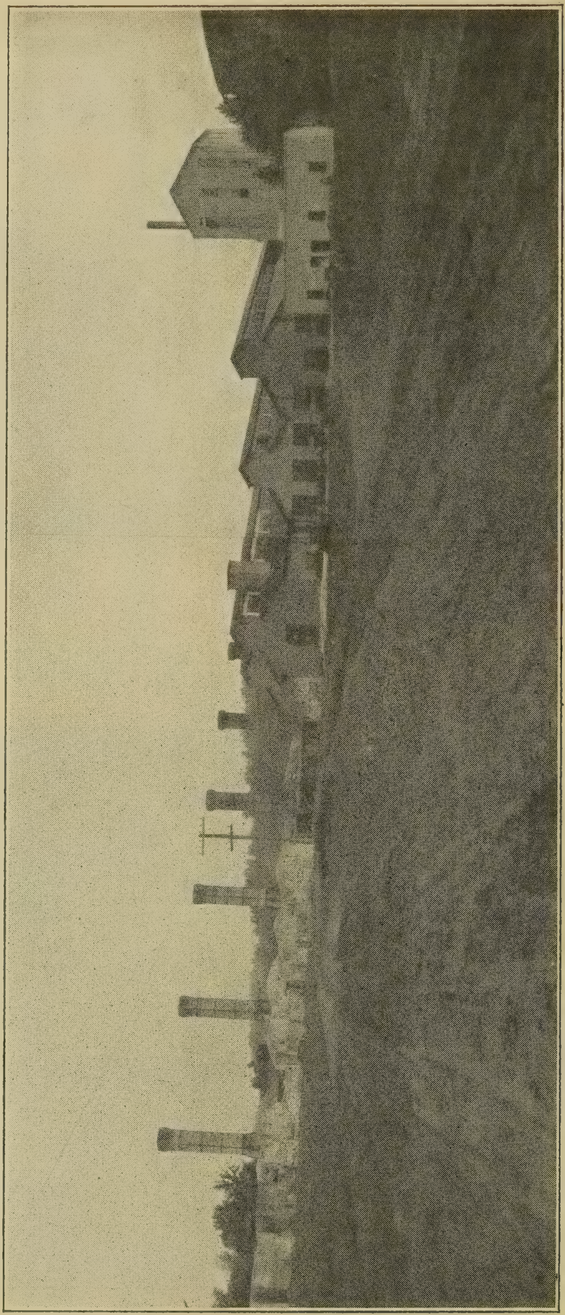

FIG. 5.

In 1871, Pottsville fire clays were mined in Lewis County and shipped to a fire brick works at Cincinnati. It is also stated that the plastic fire clays were made into fire brick at Bellefonte Furnace near Ashland, Boyd Co.

The first Olive Hill clay was shipped in 1883 to the Ironton Fire Brick Works at Ironton, Ohio, and the material was found so satisfactory that soon plants in Ashland, Cincinnati, Sciotoville and Louisville were using it.

About this same time, plastic fire clays were worked at Amanda Furnace, Ky., although they may have been worked at a still earlier date.

In 1885 the Ashland Fire Brick Company constructed a plant at Ashland, followed by the erection of another plant at the same place in 1890 by the Clinton Fire Brick Company. The latter company sold its plant to the former a few years later.

The Louisville Fire Brick Works, at Highland Park, Jefferson County, was started in 1889.

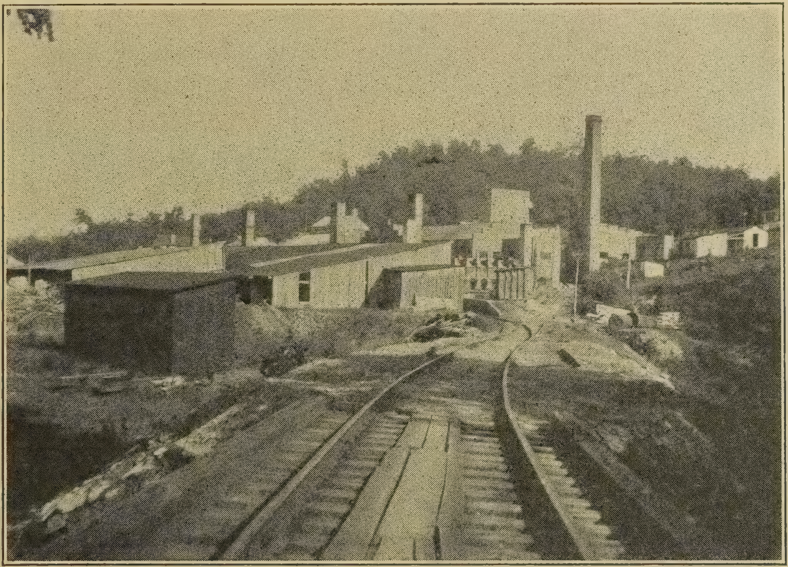

Fig. 6.—Plant of Ashland Firebrick Co., at Hayward, Carter Co., Ky.

It was not until 1895 that a plant, that of the Olive Hill Fire Brick Company, was built at Olive Hill. This was supplied from the Old Burnt House mine, now worked out, but said to have a deposit of fire clay 27 feet thick.

There followed then at intervals additional plants as follows:

1900. Ashland Fire Brick Company, Hayward, Carter Co.

1901. Harbison-Walker Refractories Company, Olive Hill, Carter Co.
1903. Kentucky Fire Brick Company, Haldeman, Carter County.
1909. General Refractories Company, absorbed plant of Olive Hill Fire Brick Company.
1911. Louisville Fire Brick Works, Grahn, Carter County.
1912. General Refractories Company, Hitchins, Carter County.

In addition Chas. Taylor's Sons of Cincinnati have taken over the former plant of the Tygart Fire Brick Company at McCall, Carter County.

These plants have an aggregate daily capacity of 535,000 expressed in terms of 9-inch brick.

While many of the mines are operated to supply local plants, there are others which are either owned and operated by fire brick manufacturing firms located outside of Kentucky, or by clay miners who own no plants.

Cornell University
Ithaca, New York

DEVELOPMENTS IN 1921 IN ELECTRIC VITREOUS ENAMELING FURNACES[1]

By James W. Carpenter

ABSTRACT

A summary of the new installations of electric furnaces during 1921 for vitreous enameling work with descriptions of various types of furnaces and operating data from various shops.

Progress of the most pleasing nature in the application of electric heat to vitreous enameling has been recorded during 1921. In that time industrial conditions in general have not been satisfactory and in the metal trades particularly there has been an extreme of depression. Despite this abnormal condition there has been a rapid development in electric enameling with new installations and improved methods of operation. A widespread interest has grown in this new field of the electric furnace and present indications point to a rapid expansion in electric furnace usage with the improvement gradually appearing in business conditions.

It was the privilege of the writer in association with Mr. C. W. Mehling to offer at the 1920 meeting of the American Ceramic Society a report on the operation of the first commercial application of electric heat to vitreous enameling in the factory of the St. Louis Brass Mfg. Co. It is the purpose of the present paper to give in brief fashion the advancements in the use of electric heat for vitreous enameling during 1921.

Since that report on the St. Louis Brass Mfg. Co. furnace, the installation has remained in steady operation and has continued its uniform production of white enameled reflectors of various shapes. It has also been used for color work, pipe work and cast iron jobs. In all cases the results have been of the very best quality. This furnace has been subjected to extremely hard usage as it was operated on night shift during the spring months. It was shut down for a brief period and then placed on day time operation during the summer months. Since October it has run on night shift again, 10 hours a night and six nights a week. This continual daily shutting down, starting up and change of schedule has not had the slightest apparent effect upon the furnace. The brick work and structural work are unimpaired, the elements from external inspection appear in first class condition, and the furnace in general is in excellent shape. The maintenance during the year has consisted of one thermocouple, a small coil and four dry cells on the Leeds and Northrup control apparatus and a box of fuse links for the main fuse block of the furnace circuit. During the year the furnace has been further improved in appearance and operation by the application of a thin coat of asbestos to the outer walls. This has saved a considerable amount of heat and has given an unusually clean appearance to the furnace.

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[1] Read by Mr. Hain before the Enamels Division, St. Louis Meeting, Feb. 28, 1922.

A smaller furnace of two compartment design in the factory of the General Electric Company at Schenectady, N. Y., has been reported in *Chemical and Metallurgical Engineering* (1921) as giving similar satisfactory results. This furnace is used for the enameling of resistance tubes used in electrical apparatus manufactured by the General Electric Company. The furnace has a front chamber 48 inches long, 18 inches wide and 24 inches high, supplied with 9 kw. of electrical capacity and arranged as a preheating chamber. The material is placed in this chamber for approximately six minutes at a temperature of 570°F. It may then be moved back to the second chamber which is 48 inches long, 18 inches wide and 24 inches high. In this chamber the work is carried up to 1650°F for a period of four minutes. This second chamber has an electrical capacity of 24 kw. The data obtainable indicate that the load in the furnace will consist of 36 tubes or 27 pounds of material in one compartment and that the supporting tray will weigh approximately 30 pounds. It has been estimated that this small furnace has increased the production of the department where it is used about 50% over the old oil furnace and very favorable operating costs with the electric heat have been obtained in comparison with the previous requirements of 6 gallons of oil per hour.

The value of the electric furnace for another type of small piece enameling has been shown in the initial installation in an Illinois watch factory. This particular furnace is of the rotary type with a narrow refractory block supported on stools and rotated through three separate chambers. The plates to be enameled are sprinkled with the enamel in the dry process and then placed in the furnace and carried around on the rotating refractory. This furnace has given exceptionally satisfactory results in the quality of enamel finish.

The first application of the electric furnace to the enameling of stove parts has been made during the year in the factory of a Rochester, N. Y. stove company. The furnace for this work is somewhat similar in design to that of the St. Louis Brass Mfg. Co. although it is smaller in size and has an electrical rating of 95 kw. The approximate overall dimensions of this furnace are 8 ft. high, 9 feet deep and 7 feet wide. The heating chamber is composed of an upper and lower chamber about 42 inches wide, 5 feet deep and 23 inches high. The wall construction is approximately as follows: Fire brick lining on the inside with a minimum thickness of 4$^1/_2$ inches at the side walls of the upper chamber and a maximum thickness of 9 inches at the arch. The lower chamber walls are also 9 inches in thickness. This fire brick enclosure is surrounded by a 9-inch lining of Sil-o-cel and there is then an outer shell of a single course of common red brick. The door consists of 4$^1/_2$ inches of fire brick facing with 4$^1/_2$ inches of Sil-o-cel, carried in a cast iron frame.

At present this furnace is being operated at from 1250 to 1350°F for the enameling of cast iron stove parts. Four colors of enamel are being produced—white, black, gray and blue. The surfaces of the work are not pitted and when the castings are fractured, the enamel adheres very closely to the line of cleavage. Very shortly it is planned to put Armco iron parts used for gas ranges through the furnace when the temperature will be approximately 1600°F. The furnace is now operated at night from seven P.M. until the day shift of workers arrives at the factory and the power consumption approximates 10,000 kw. hr. a month. It has been determined that the production of the furnace is easily 700 pounds of metal per hour on cast iron parts enameled at a temperature of 1250°F.

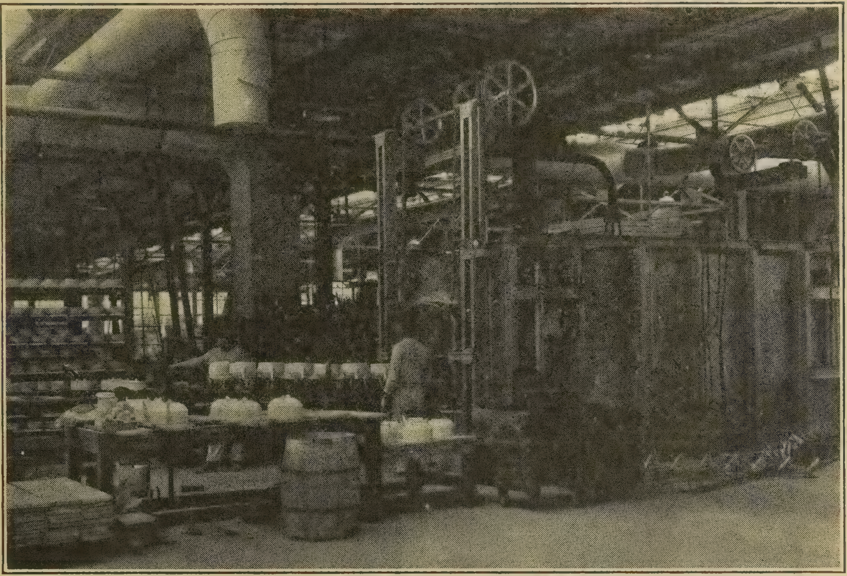

Fig. 1.—Electric furnace for kitchen ware.

For the production of hollow ware an interesting installation has been made in a Chicago factory. This unit is arranged for double end operation. The inside length of the furnace is approximately 15 feet, divided into two equal sections and there is a door at each end. The width of the burning chamber is 42 inches and the height is approximately 2 feet. The power rating is 235 kw. for operation on 440 volts, 3 phase, 60 cycle service. The company operating this particular furnace is reported as being very pleased with the results of the few months of operation. They are turning out exceptionally good work and have entirely eliminated rejects due to improper burning. They have been able to increase the number of pieces placed on a fork from 14 to approximately 24 for a given charge and can thus use 100% of the hearth space.

Another large furnace placed in operation during the year is devoted to the enameling of bath tubs and such articles. This unit is a double chamber furnace constructed for operation on the old gas and coal furnace schedule of $2^1/_2$ tubs per hour but the electric furnace has gone right along with a considerably better production in each chamber. This furnace is notable for low operating cost, uniform heat, advantages obtained through automatic control of temperature, elimination of rejects and simplicity of operation.

Some of the operating data at present available on furnaces of the foregoing types are given in the following paragraph.

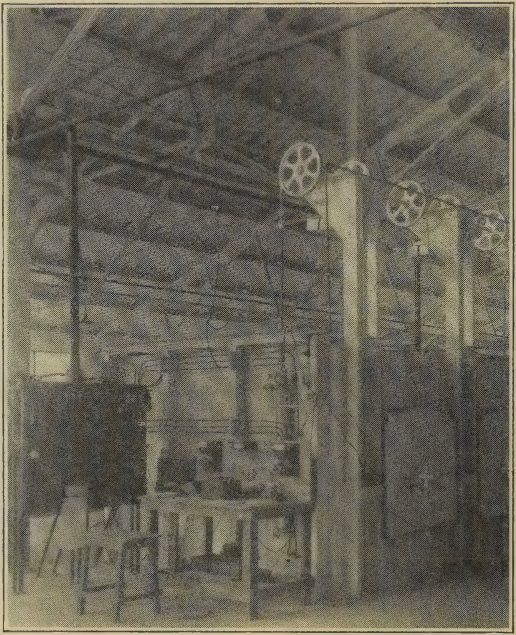

FIG. 2.—Electric furnace for bath tubs.

One furnace is arranged to deliver at least 25 heats of 110.4 lbs. per hour, as follows:

Supporting racks	60 lbs.
Steel ware	32 lbs.
Enamel	18.4 lbs.
Gross production per hour	2760 lbs.
Net production per hour	1260 lbs.

The net efficiency is approximately $6^1/_2$ lbs. of material burned per kw. hr. of power consumed. At the present time the furnace operates at 1750° F with the maturing temperature of the enamel at 1550°F.

For the furnace from which this data were secured, it was predicted that the quantity of tin oxide used in the enamel can be materially decreased because of the very positive temperature at which the electric furnace operates at all times. Likewise the production has been increased approximately 50% per unit of floor space and it seems probable as regards installation costs that the increased production will offset the greater first cost of the electric furnace.

In one factory two electric furnaces have replaced three coal furnaces, that is, the production of two electric furnaces is equivalent to the production of three coal furnaces. The cost of the coal itself, plus the labor for unloading coal and the firing, and the labor for removing the ashes, was equal to the cost of power consumed by two electric furnaces. This calculation was based upon 20-hour per day operation with coal at $4.60 per ton on the siding, and electricity at 1.8 cents per kw. hr. In addition, the three coal furnaces required 7 men, 2 shifts each, while the two electric furnaces require only 4 men, 2 shifts each. The labor costs in the case of the three coal furnaces amounted, therefore, to $56 a day while with the two electric furnaces the labor cost was only $32 a day. With the lower labor cost and the equal fuel and power costs, the two electric furnaces have a net daily operating cost approximately $20 lower than that of the three coal furnaces.

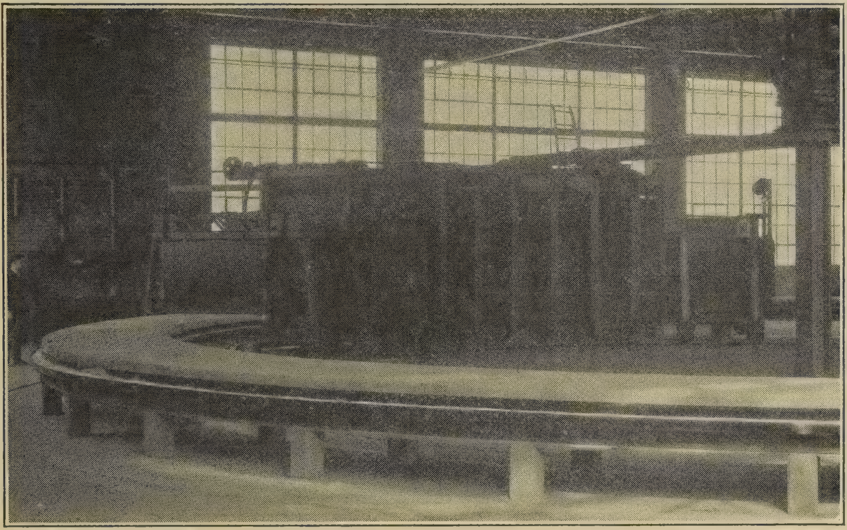

FIG. 3.

New Design-Movable Furnace

During the past year plans were formulated for a revolutionary idea in enamel burning. The fundamental thought in this new design of furnace is to carry the furnace over the ware to be enameled instead of placing the ware inside a stationary furnace. The initial installation based upon this principle was designed for a large enamel ware factory in Pennsylvania. The equipment has been installed and tested out for several days and it is expected that active production will be carried on just as soon as the factory building has been completed.

This installation may be described briefly as follows: There is a stationary circular platform which is 54 inches wide and 60 feet in diameter from center of table to center of table, giving a circumference of approximately 186 feet. The ware is to be placed by hand on this platform and the furnace proper revolves over the platform, moving along on a standard railroad gauge track. The furnace chamber is 21 feet in length in the main section and attached to each end of this main chamber there is a hood 8 feet in length. There are doors at each end of the main chamber as well as at the ends of the hoods. These hoods are intended to prevent excessive heat losses from the main chamber as the doors are opened constantly just high enough to clear the ware.

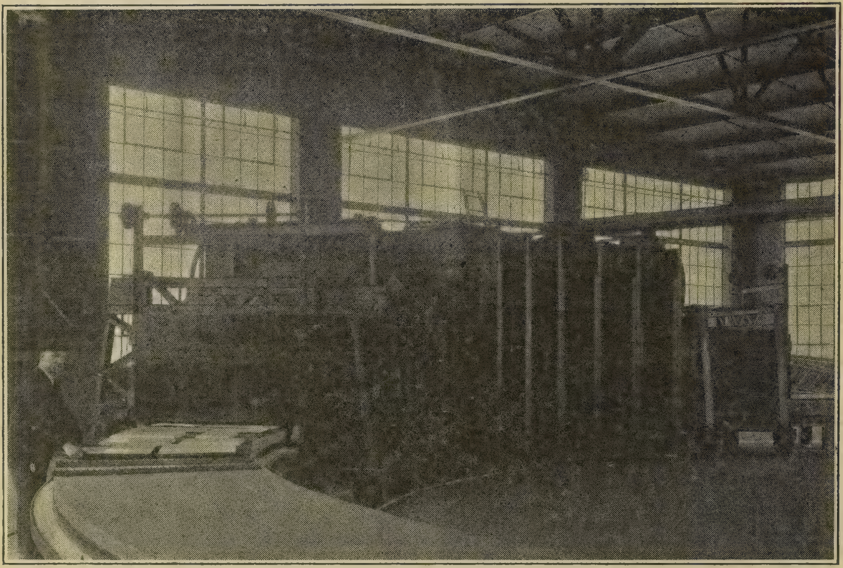

FIG. 4.—Moving furnace—stationary ware.

The furnace is driven over the platform by a variable speed motor with a range of from $4^1/_2$ feet to 9 feet per minute, and as it is to be operated at an average speed of 7 feet per minute, the ware will be covered by the main heating chamber for a period of 3 minutes.

This furnace is supplied with 600 kw. of electrical capacity but it is expected that it will be operated most of the time with an input of 500 kw. The maximum capacity of enamel ware production is 3000 pounds of material an hour and the furnace can take care of 2430 square feet of ware in that time.

The present plans call for operating procedure to consist of placing the ware on the table top by hand and as the chamber will make a complete revolution in 24 minutes, there will be 21 minutes in which to unload the table. It is expected that labor cost can be materially reduced as ordinary labor can be used for all the work and the men will be able to keep busy all the time loading and unloading ware. The racks will be of very light material as they are placed on a level table and are not handled with force. They are supported along their full length and will accordingly not sag. The furnace can be operated at any desired temperature in the enamel range up to 1850° for ground coat.

It will be very interesting to see the results obtained from this installation and to study the possibilities of this method of operation in large enamel shops.

The information set forth in the foregoing covers the principal developments of the year of 1921. The notable advances that have been made foretell greater developments in the years to come and we may look cheerfully to the future for far-reaching advances in this phase of the Ceramic Art.

Discussion

Mr. LINDEMANN:—Mr. Chairman, I visited the St. Louis Brass Works last night, and watched their electric furnace in operation. Mr. Mehling made the statement then that they could turn out twice as much work as with a coal furnace, but I can not understand why, if you maintain the same temperatures, there should be any difference in the production of one furnace against another. There are furnaces built today which can, without any question, maintain a temperature of 1600° to 1700°F in continuous operation, putting in successive loads as fast as is possible. Why can't you turn out as much work there as in an electric furnace?

Mr. HAIN:—Here is an illustration of an enameling furnace handling hollow ware. The resistor is near the work and very rapid action results from that resistor and very delicate temperature control is obtainable.

It has been found with electric furnaces not only of this type but electric furnaces for steel heat treating and for melting brass and non-ferrous metals, as well as arc type furnaces in melting down steels, that electric heat was very much more rapid than that from other types of fuel. That has been explained by the fact that most all of the heat is transferred from the ribbons by radiation rather than by convection gases, radiation being a rapid method of transference of heat. In this type of furnace, we have estimated that probably 85 per cent of the energy is transferred from the element, which generates the heat, directly into the work by radiation and the balance by convection. That is the explanation of the speed which you get out of electric furnaces. It is not only notable in high temperature furnaces of this kind but also notable in japanning at low temperature, and it is universal in electric furnaces. That is the explanation that has been given for it.

MR. LINDEMANN:—The fact that it is generally conceded does not answer my question.

MR. HAIN:—I have attempted to explain that the fact that the energy is obtained by radiation, rather than convection, is the answer.

MR. JAEGER:—Mr. Chairman, from observing operations on both types of furnaces, I believe that question can be answered by citing a simple example. In putting a heavy casting into an ordinary muffle type furnace anyone who has seen the operation will recall that the bottom and side tile get dark, which would not be the case in an electric-heated furnace. The electric-heated resistors will not cool off as they are constantly giving out energy.

CHAIRMAN POSTE:—In other words, Mr. Lindemann's hypothesis, that you do maintain the same temperature, is not realized.

MR. LINDEMANN:—Mr. Poste, we observed last night, that with twenty-five ordinary electric reflectors, the recording pyrometer showed that when first loaded the furnace temperature dropped one hundred and fifty degrees. I can show you coal-fired furnaces taking eight hundred pounds of cast iron where the furnace temperature would not drop over forty degrees.

CHAIRMAN POSTE:—What are the details as to the location of the end of the thermocouple in two places?

MR. LINDEMANN:—The end of the thermocouple was within a few inches of the resistor ribbon, and in the coal-fired furnace it was placed in the rear end of the furnace about half way up and projected six inches into the furnace, which is eleven feet in length.

MR. SWEELY:—I might be able to help out a little. It is a question not only of location of installation but also of the type of installation. I would like to ask Mr. Lindemann if his thermocouple is enclosed in a tube?

MR. LINDEMANN:—No, it extends through a tube, the couple itself being exposed.

MR. SWEELY:—We have four coal-fired furnaces and this electric furnace as shown on the back of this sheet, which gives us the opportunity to compare the two furnaces. We have put couples into the back of our coal-fired muffle furnaces, which are the standard type, the old type. I am not speaking of the carbon muffle or the gas-fired or oil-fired type, but the old fashioned coal-fired muffle furnace. When putting a load in we get the same temperature drop in introducing the charge as we get in the electric furnace. However, it is not a question of drop in temperature of the furnace but a chilling of the air within the furnace. Convection plays a large part in the heating of the ware. As soon as the cold ware is introduced into your furnace, a circulation of air is started. If you chill the air it will fall, the hot air will rise and, naturally, the air is chilled in the vicinity of the couple. The result is there will be a sharp drop when introducing the ware.

That has been our experience with either type of furnace, but the load introduced in the electric furnace is larger, and the heat is there. With the coal-fired muffle we are using, the furnace will not maintain its heat with a heavy charge, due to the fact that the muffle tile will not conduct heat fast enough to the muffle chamber. That, I think, is the explanation of the difference.

Mr. KALLSTEDT:—I would like to ask how long Mr. Sweely figures it takes to heat up this larger furnace from a cold start?

Mr. SWEELY:—We have never allowed the furnace to cool off. We heated it up once. The first time it was heated up, we had the condition of wet brickwork and all that sort of thing to contend with, which is not a fair test. Any furnace will heat up slowly when first built.

The best idea I can give of the way the furnace heats is when the furnace is shut off. We shut the furnace off on Sunday morning at six o'clock, as we do not operate on Sunday, and start the following morning at about three, and the temperature will be from 1000° to 1200°F when we turn the current on, and it will require about two hours to bring the furnace up to heat, but the furnace will have to be kept on an hour or two longer to get maximum production. It is a case of storing a certain amount of heat in the brickwork.

Mr. KALLSTEDT:—I can readily see that the radiation loss would not amount to a great deal, because the furnace takes care of that. However, if operating conditions were such that you had to shut down your furnace for a week, would it not pay to keep the furnace hot? I have seen intermittent gas-fired furnaces ready to operate at 1750°F from a starting temperature of 600°F in forty-five minutes. This I believe would be impossible with this furnace.

Mr. SWEELY:—I do not think it would pay to keep it hot. We do not keep it hot over Sunday, although the furnace would only be taking current about one-fifth of the time.

Mr. RIESS:—I visited the St. Louis Brass Co. last night, and was advised it took about twelve hours to heat that furnace from a cold to a working temperature.

Mr. STALEY:—The electric furnace we have—we use about the same size —takes us about twelve hours, and you get exactly the same amount of current that it takes to maintain the furnace. We maintain our furnace with about seventy kw. per hour. After we get it up, it takes twelve hours of seventy kw. to keep it up.

Mr. LINDEMANN:—The reason I asked the question was to start a discussion, because I had in mind that, possibly due to additional expense of installation and the expense of operation, it probably was a fact that anyone who owns an electric furnace would operate the same more carefully and drive his men to get more production than under other circumstances.

We had a similar experience some years ago on japanning, where the question of installing electric ovens came up. At that time, taking into consideration what was necessary to operate the electric japanning oven, we applied the same conditions to a gas oven, and increased our production nearly fifty per cent. I believe similar conditions account for some of the advantages in the operation of electric furnaces in comparison with coal-fired muffle where precautions are not taken. I would like to ask Mr. Sweely whether he has any particular reference to that subject?

Mr. SWEELY:—I should not want anyone to get the impression that I am selling electric furnaces or that we believe an electric furnace is the only thing for enameling. We have put this furnace in, and so far we have no cause to regret it.

As to getting down to actual cost, the furnace was started in December and, like many plants that are making money, we have not worried about the cost. The figures presented in this paper are approximately correct. I have not checked them over personally, but that will probably be done sooner or later in the plant. I think there are a number of furnaces that are very good.

I would like to call the attention of the Ceramic Society to a furnace that is in operation in the Chicago district—a gas-fired furnace without a muffle, which is giving good results. I have seen both of them in operation and they are doing good work. Whether they are doing poorer work than the electric furnace, I do not know.

CHAIRMAN POSTE:—Is there anything else bearing immediately on the paper that has just been presented?

Mr. RIESS:—I would like to ask Mr. Sweely whether he had that electric furnace in operation long enough to make comparative costs.

Mr. SWEELY:—We have not as yet. That is the point I was trying to make.

CHAIRMAN POSTE:—Has anyone any data on that point?

MR. MAHONEY:—I would like to ask Mr. Sweely if he has experimented with leaving that furnace run over Sunday and then cutting it down and turning it on at three o'clock to make a comparison as to whether it was cheaper to keep the furnace at heat or let it cool down.

MR. SWEELY:—The plant engineer and myself have been having a little controversy on what is the best policy. I wanted the furnace in full heat on Monday morning, but as yet we have not settled the matter.

MR. WENNING:—The cost of operation of an electric furnace in one stove factory runs about three hundred dollars a month. In Canada they are running seven furnaces at about half the cost.

HEAT TRANSMISSION, WITH SPECIAL REFERENCE TO THE STOKER FIRED BOILER[1]

By R. M. Howe and S. M. Phelps[2]

ABSTRACT

It has been demonstrated that the temperature within the brickwork depends to a very large extent upon the pressure conditions within the furnace. When the gases are under pressure they penetrate the brickwork, impart their heat, and raise the temperature above that which would result from simple thermal conductivity. When the gases are under draft, cold air is drawn through the brickwork into the furnace and it exerts a cooling effect. Spalling is therefore associated with furnace pressure; when positive, spalling is greater than when negative. This is due to the fact that spalling is a function of vitrification, which in turn is a function of temperature. It is believed that these results may explain the lack of concordance in those pertaining to thermal conductivity. They probably represent heat transmission in a number of cases and are therefore higher or lower than conductivity according to the direction of the gas flow.

When high grade coal was available at a low cost there was little necessity for the study of furnace efficiency. Today this subject is being given serious consideration wherever coal is burned. The forced draft automatic stoker is a logical outgrowth of the effort to burn this fuel more economically. With its application the efficiency obtained with bituminous coal has been increased from 50 to 65 per cent, while that obtained with semi-anthracite has increased from 70 to 75 per cent. Some coals that could not be used in hand-fired furnaces are now being utilized with great economy.

The importance of greater efficiency may be illustrated by the fact that a medium grade coal (11,000 B.t.u.'s) burned with an efficiency of 65 per cent is equivalent to a high grade coal (14,500 B.t.u.'s) burned with an efficiency of only 50 per cent. A low grade coal (9,000 B.t.u.'s) would have a similar value if burned at an efficiency of 80 per cent. The following table shows the relative values of different grades of coal when burned under different degrees of efficiency for the evaporation of water in boilers. These figures are based on evaporation from, and at, 212°F.

Table I

	50% Efficiency		65% Efficiency		80% Efficiency	
B.t.u. per pound coal	Evaporation per pound coal	Pounds coal per h.p. per hour	Evaporation per pound coal	Pounds coal per h.p. per hour	Evaporation per pound coal	Pounds coal per h.p. per hour
7500	3.8	9.0	5.0	6.8	6.2	5.5
9500	4.9	7.0	6.3	5.4	7.8	4.4
12500	6.4	5.3	8.4	4.1	10.3	3.3
14500	7.5	4.6	9.7	3.5	12.0	2.8

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[1] A contribution from the Industrial Fellowship of the Refractories Manufacturers Association, Mellon Institute of Industrial Research, University of Pittsburgh, Pittsburgh, Pa.

[2] Read before Refractories Division, St. Louis Meeting, Feb. 28, 1922.

It has been noted, however, that the service obtained from the refractories is usually shorter when used with low grade fuel burned by forced draft. This decreased service is not due to higher furnace temperatures nor to increased slag action. The refractories do have a higher tendency to spall. It was suggested that this condition might be due to changes in furnace pressure when automatic stokers replaced hand firing.[1] Accordingly, a study was made of the influence of furnace gas pressure upon heat penetration.

Fire clay tile were made so that temperature readings could be obtained at several distances from the hotter surface. These tile were placed in the door of a furnace, laid up with fire clay, and heated under the condition indicated below. The temperature measurements were checked every hour and finally recorded when equilibrium was established. The position of the tile was not disturbed until the tests were complete.

TABLE II

Furnace Temperature	1340°C	1340°C	1340°C	1220°C	1220°C	1220°C
Pressure of furnace gases (inches of water)	+1.00	+.05	−.30	+.95	+.05	−.30
Temp. of fire brick $^1/_2$ in. from hot surface	1305	1265	1105	1105	1075	900
“ “ “ 1 in.	1270	1210	1020	1035	965	800
“ “ “ 2 in.	1125	1040	800	900	770	620
“ “ “ 3 in.	1040	950	720	800	660	490
“ “ “ 4 in.	845	745	515	665	510	355

Upon examining these data, it becomes evident that heat penetration depends very largely upon the pressure of the furnace gases. It is not only a function of the thermal conductivity of the brick, but also depends upon its permeability. The temperatures recorded at a pressure of +.05 inch of water probably approximate equilibrium conditions for a tile of that character, thickness, and conductivity. The temperatures recorded at a pressure of +1.00 inch of water indicate the extent to which the permeating gases imparted heat to the brickwork. The temperatures recorded under a draft of .30 inch of water show the cooling effect of cold air that was drawn from the room, through the brickwork, and into the furnace.

Consequently, the temperature within the brickwork of a furnace will be several hundred degrees higher when operated under pressure than when operated under draft conditions. Pressure, therefore, accelerates vitrification, which is a function of temperature and which progresses rapidly in first-quality fire brick at about 1350°C. As fire brick vitrify they become less resistant to temperature change and spall more rapidly. In view of these facts a higher tendency to spall is the natural and unavoidable result of changing from draft to pressure, reducing the draft, or increasing the pressure of the furnace gases.

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[1] This suggestion was made by Mr. J. E. Harlow, Chief Engineer, M. H. Detrick Co., whose co-operation is hereby acknowledged.

In obtaining the experimental data under discussion, it was necessary to lay up the tile in fire clay so that the proper draft and pressure could be obtained under laboratory conditions. It is obvious, however, that the influence of these conditions would be far greater were the fire clay joint omitted, as is sometimes the case in actual service. This being the case, it might be beneficial to omit the joint where the furnace is operated under draft conditions. On the other hand, it might be possible to minimize the effect of pressure in producing a high temperature within the brickwork by using a dense burning material in the joints. Care should be exercised, however, in selecting bonds of this type for they are very often of low refractoriness and consequently leave the joint open as they melt and run.

The joint should never be greater than $^1/_{16}$ inch in thickness.

A thin wash (less than $^1/_4$ inch) of dense burning cement can also be applied with advantage to the entire furnace lining. When this vitrifies or melts at furnace temperatures it retards gas penetration and in that way decreases spalling by virtue of a lower temperature within the brickwork. While joints must always be made as thin as possible, these washes may be applied more thickly; softening of a joint may cause the collapse of the brickwork while a wash supports nothing but its own weight. The deposition of an easily fusible ash produces the same effect as may be secured by the application of a wash but, of course, is accidental and cannot be relied upon.

The application of these results is not limited, however, to this particular problem. They have a direct bearing upon the study of thermal conductivity and upon the application of the load test.

The heat transmitted through a refractory is not necessarily a measurement of its thermal conductivity. It depends upon at least two factors—the thermal conductivity of the material itself and the penetration of hot or cold gases. Heat transmission and thermal conductivity equalize when there is no circulation of gas within the material. Heat transmission is greater or less than thermal conductivity when hot or cold air is drawn through the specimen under consideration. The type of furnace used will effect thermal conductivity results and this fact may explain the lack of concordance of those on record. An electrically heated furnace should reduce errors in thermal conductivity measurements to a minimum, for no gases are in rapid motion; gas-fired furnaces are usually under high pressure or draft, depending upon whether a blower or stack is relied upon to supply the air for combustion.

These results also limit the application of the load test. They demonstrate that the drop in temperature is very sudden in uninsulated walls.

Consequently, the major portion of a fire brick will be at a sufficiently low temperature to carry the load of the average installation. The load test is, therefore, directly applicable only to muffles and cases where insulation is applied.

They also throw an important light upon the action of slag on fire brick. From these data, it is evident that the slag will penetrate only to a slight extent before it becomes chilled. Before going further it must dissolve the brickwork, after which there is a temperature readjustment allowing further penetration. The action is, therefore, primarily a junction of the fluxing power of a given slag. These conditions must not be overlooked in the future development of a slag test, as they have in the past. Results obtained by heating a brick throughout and treating with a small quantity of slag have no practical application, for they measure penetration and not the chemical action of the slag. Further studies of heat penetration are now under way and additional data have already been obtained. These data, however, are not applicable to the present discussion.

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Discussions

By J. E. Harlow:—Our product consists chiefly of a flat suspended fire clay tile arch. This arch is used as a roof over the enclosure where all kinds of fuel are burned and where all kinds of hot gases travel. Its chief function, of course, is to reflect heat, thus assisting and maintaining combustion. The temperatures reached vary from 1100°C to 1400°C.

The chief requirements of a flat suspended arch are proper position in the furnace, freedom to expand and contract without stress or strain, and a good refractory.

The requirements of a refractory for a suspended arch of the best design are high fusing temperature, high resistance to corrosion, and abrasion from high temperature gases and high resistance to spalling.

Most hand-made tile have sufficiently high fusing temperature to resist the temperatures encountered in boiler furnaces. There are furnaces, where the temperature is higher and where the heat is termed "soaking heat," that require more special attention to fusing temperature. These are found chiefly in the metallurgical processes where high temperature and slow gas velocity present a different refractory problem.

Resistance of refractory to corrosion and abrasion of gases is a more serious problem, especially with fuels of high ash content or fuels containing a basic compound.

Resistance to spalling is the most serious problem. Fire clay manufacturers can assist as far as the problem of proper mixture of flint, plastic and calcined clay is concerned; also in the degree of burn. But the arch designer can assist very materially by making a shape easily manufactured and free from entrant angles.

These requirements are obvious, but as the problem becomes clearer to our minds, the action of heat within the tile becomes a question. Observation and analysis have shown that spalling can be reduced by exposing only one plane or slightly curved surface to the heat. Success with this idea leads by analogy to the prevention of heat penetration into the joints between the surfaces of the tile.

This is a difficult matter for the reason that fire clay tile manufacturers do not always succeed in making tile with plane surfaces and square angles and the action of fire clay used as mortar or grout is very uncertain. It may be solved by some high temperature cement coating, and it may be solved by the accidental presence of a low fusible ash. The writer is inclined to the use of common salt, but is well aware of the objections and makes use of that in a very limited way, dictated, of course, by observation of hundreds of various furnaces in actual operation. The present paper confirms our reasoning in this problem, and suggests many other problems. One of them is the depth of tile to be used in a suspended arch.

M. H. Detrick Company
Chicago, Illinois

By P. Nicholls:—Most engineers concerned with heat transmission have recognized that leakage of air through a material would affect its apparent conductivity, and consequently also the temperatures through its section, but the authors are to be congratulated on being the first to demonstrate experimentally what may be the order of value of such changes.

It is unfortunate that the paper does not give fuller details of the apparatus used, and in particular of the tile blocks themselves. Were, for instance, these blocks four inches thick, so that the 4-inch temperatures are those at the surface? If so, such temperatures would give some relative idea at least of the quantity of heat transmitted if the air temperature near the surface were known, and if the face was not too much shrouded by other parts of the apparatus.

Were the holes for the thermocouples parallel or at right angles to the face of the tile, and were proper precautions taken that the air was not short-circuited by such holes, as this might materially affect the temperatures indicated by the thermocouples? Since the same blocks were used throughout the tests, was there any surface change that would tend to clog up the pores and thus successively reduce their porosity?

In lack of a knowledge of the value of the heat flow it is not worth while attempting to form any idea of the amount of gas or air passing through the tile, but some interesting confirmation of the effect of leakage on the temperatures can be made from a study of curves representing the results, which are plotted on Fig. 1.

Curves 1, 2 and 3 are the three where the furnace temperature was 1340°C, and 4, 5 and 6 where it was 1220°C. The dotted parts of the curves are on the assumption that the furnace temperatures existed about

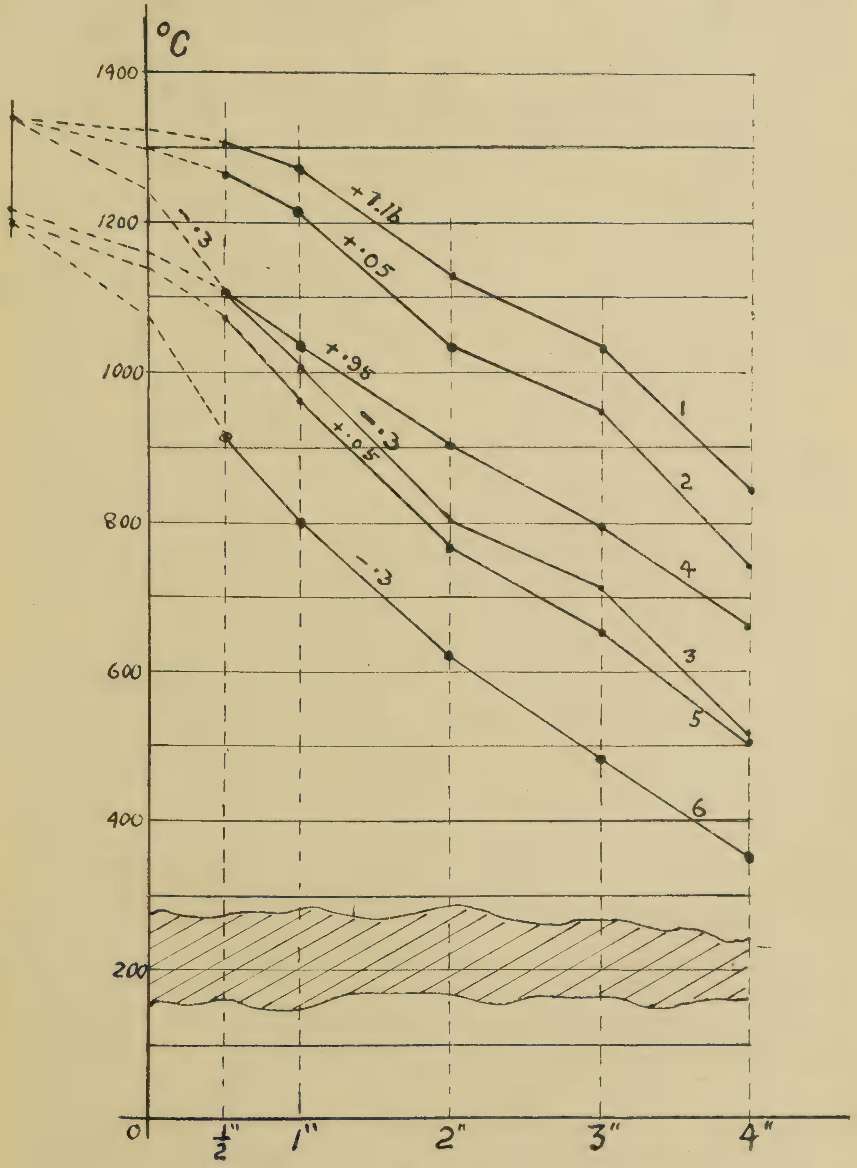

Fig. 1.

one inch from the inner face of the wall and are, of course, uncertain as to their correctness.

It would appear that possibly one or both of the temperatures at the 2-inch and 3-inch points are in error. Such temperatures are difficult to obtain accurately—especially with holes at right angles to the face, that is in line with the direction of heat flow—due to the disturbing effect of the holes themselves and to the higher conductivity of the metal of the couples.

Assuming that gas or air passes through the wall, what will be its effect on the temperature? Consider the case of the hot gases passing from the furnace to the outer face. It can be assumed that the rate of flow is constant when practically constant conditions have been established. Since the gas is cooled down in passing through, the only way it can have parted with its heat is to have given it up to the material, which in turn transmits it to the surface. Before constant conditions are reached, some of this heat will also be used to raise the temperature through the wall, but finally the heat taken up from the gas by any small piece of material will become constant, and be equal to the increase in the rate of flow in the material at that point.

The general effect of the passage of the gas is to add through the material what is equivalent to a source of heat supply equivalent in action to generation of heat at all points, and this action is superimposed algebraically on the transfer by direct conduction from the inner hot surface. Also the temperature of the gas at any point must always be greater than the material in contact with it, though this difference may be small.

The general effect on the temperature curve can be seen by a simple consideration. Fig. 2 represents any small section, at right angles to the direction of heat and gas flow, and of thickness AB. Divide this equally at C. Then the heat flowing across CC' is greater than that across AA' by the quantity of heat absorbed from the gas by the thickness AC. Similarly, the flow across BB' is greater than that across CC'. Assuming that the conductivity coefficient of the material does not decrease with temperature increase, it follows that the drop in temperature from C to B is greater than that from A to B, and thus the temperature curve would be concave toward the temperature axis.

Similarly in the case of air passing from the outside to the furnace, the temperature curve would be convex.

In addition to this, it has been pretty well established that the conductivity of ceramic materials increases with the temperature, which will again bow up the temperature curve, so that with air inleakage, the departure of the curve from a straight line will be the resultant of these two tendencies.

Again, because the outer surface temperature is higher when the hot gases pass outward than it would be if there were no gas transfer, therefore

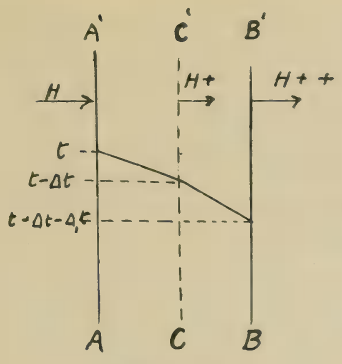
A'
C'
B'
H
H+
H++
t
t-Δt
t-Δt-Δ₁t
A
C
B

Fig. 2

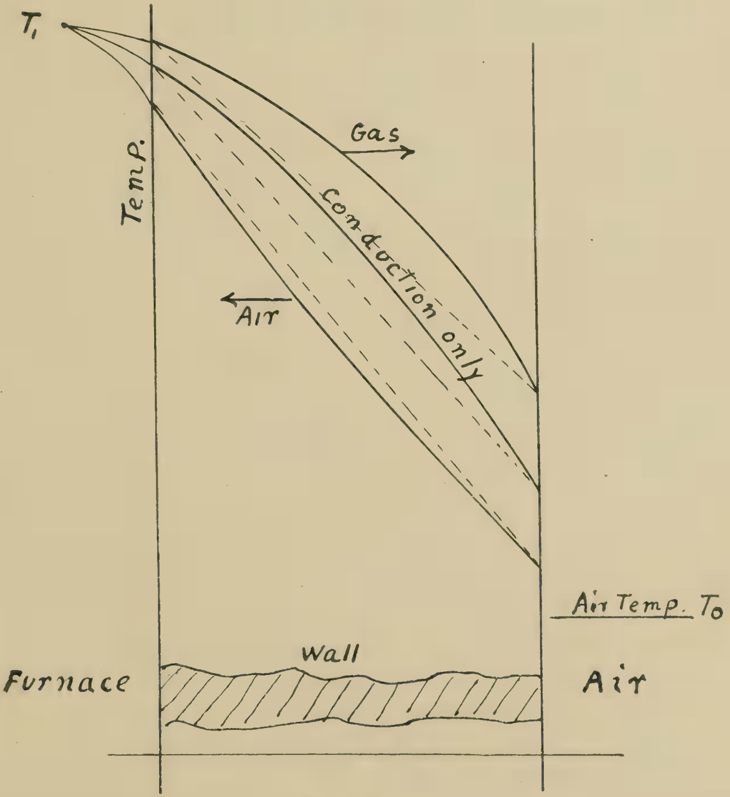
T₁
Temp.
Gas
Conduction only
Air
Air Temp. T₀
Wall
Furnace
Air

Fig. 3

there will be a smaller quantity of heat transferred from the furnace by direct conduction. Similarly with passage of air inward the flow of heat by direct conduction only will be greater. This argument should strictly be applied to the rate of change at the inner surface, but the same reasoning still applies, and more so, in as far as the gas or air temperatures, respectively, differ from that of the material. These tendencies in the two cases are in opposite directions and would counterbalance each other as far as general comparisons go.

Fig. 3 shows these expected curves plotted for shape only, and it is apparent that those in Fig. 1 as found by the authors exhibit the same tendency, though there is not as much curvature distinction between that for 1 inch and .05 inch pressure, as between the .05 inch and the −.3 inch.

Fig. 1, showing the results of the tests, gives a comparatively large difference between the temperatures at each surface for gas and air leakage. It is to be expected that the method of test accentuates this greatly compared with what would be found in actual furnaces. The leakage must have been comparatively high, and possibly the heat reserve in the furnace was comparatively small and the velocity of the gases over the surface low, so that the inleakage of air produced at the inner surface a large increase in the air film thermal resistance.

Probably more detailed investigations into and determination of the physical actions causing spalling are needed before it is safe to make assured deductions, as it would appear to be a choice between higher temperatures with smaller rates of change in the case of outward flow, and the reverse for inward flow.

If the inward flow is desired, the remedy would seem to be to connect a space behind the brickwork with the pressure supply, and it should thus be possible to maintain a greater pressure than that above the fuel bed. This should be particularly easily arranged for in the case of the majority of arches.

REPLY by R. M. HOWE:—It is unfortunate that Mr. Nicholls should be forced to ask for information regarding testing details, but these were omitted from this preliminary report for the sake of brevity. The tile were 9 inches in thickness, but temperature observations were not made in the cooler half as they were too low to affect the properties of the tile. The thermocouple holes were at right angles to the furnace lining. There was no apparent change in the porosity of the tile at the temperatures involved, these having been selected with this point in mind. It might be stated also that the 1200° C readings were made first.

Mr. Nicholls' discussion of curves 1 and 3 is particularly interesting and encouraging to the writer, who has read so many contradictory reports on the thermal conductivity of refractories. Thermal conductivity results obtained in well planned investigations often show variations as great as 100 per cent and rarely show a definite tendency that may be expressed graphically. While several of the points in Fig. 1. are obviously incorrect the general tendencies of these curves are similar to those in Fig. 3.

It is possible that Mr. Nicholls' suggestion regarding a pressure reservoir back of the brickwork might be applied to prevent the passage of gas from the furnace into the tile.

We are not willing to modify our original statement regarding the effect of furnace pressure upon spalling for the chain of evidence is too complete. The temperature within the brickwork of furnaces operating under pressure is greater than with those operating under draft. Vitrification is a function of temperature. Spalling is accelerated by vitrification. Therefore, it is obvious that spalling will be more pronounced where the furnace is being operated under pressure, and the usual heating and cooling takes place.

The opinions expressed by J. E. Harlow are in general agreement with those which have been formed by the writer.

In view of the results that were obtained by this very elementary study, additional tests involving tile of different thicknesses are now under way.

THE FIELD OF PORCELAIN GLAZES MATURING BETWEEN CONES 17 AND 20[1]

By Robert Twells, Jr.[2]

ABSTRACT

Field Covered.—A typical porcelain glaze formula:

$$\left.\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right) \times\ Al_2O_3\ Y\ SiO_2$$

was used. The RO was held constant, the Al_2O_3 was varied between 0.8 and 1.6 equivalents, and the SiO_2 between 6 and 16 equivalents.

Firing Test.—The glazes were applied to green porcelain discs and fired to cone 17 $^3/_4$ down, and cones, 18, 19, and 20 down in commercial kilns.

Representation of Results.—The glazes are plotted according to batch weights and empirical formula. The diagrams show the location of the best glazes at each temperature better than would statements of limits.

Best Compositions.—Under conditions similar to those used, the best glazes for temperatures between cones 17 and 20 have the following range of composition:

Clay	21.9% to 27.2%
Flint	40.8% to 51.8%
Feldspar	17.2% to 23.6%
Whiting	7.2% to 10.0%

Introduction

The field of porcelain glazes maturing between cones 9 and 11 has been carefully studied by several investigators,[3] and its characteristics are well known. Systematic information in regard to porcelain glazes maturing above cone 11 has been somewhat meagre. Recently, however, the Bureau of Standards published an article on "High Fire Porcelain Glazes"[4] covering the field maturing between cones 10 and 16. Above cone 16 there is still a lack of published information. Several months before the publication of the work of the Bureau of Standards, the writer had made a short study of some porcelain glazes maturing between cones 17 and 20. The methods employed were similar in several respects to those used by Sortwell at the Bureau of Standards; although in this case the firing was done in commercial kilns with a longer firing period. The object of this article is to publish some systematic information in regard to some porcelain glazes maturing at temperatures even higher than those studied by the Bureau of Standards. The writer recognizes the fact that similar results are not likely to be obtained except by the use of similar methods, raw materials, and body.

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[1] Research laboratories, Champion Porcelain Company and Jeffery-Dewitt Insulator Company.

[2] Read before Whiteware Division, St. Louis Meeting, Feb. 28, 1922.

[3] R. T. Stull, *Trans. Am. Ceram. Soc.*, **14**, 62–67 (1912). R. T. Stull, and W. L. Howat, *Ibid.*, **16**, 454–460 (1914).

[4] H. H. Sortwell, *Jour. Am. Ceram. Soc.*, **4,** 718–730 (1921).

Compositions Studied

The compositions of the glazes were based on the empirical formula:

$$\left.\begin{matrix} 0.3\ K_2O \\ 0.7\ CaO \end{matrix}\right) \times Al_2O_3\ Y\ SiO_2.$$

The RO members were held constant; the alumina was varied between 0.8 and 1.6 equivalents; the silica was varied between 6.0 and 1.6 equivalents. Fig. 1 shows the molecular variation of the alumina and silica in the glazes. Fig. 2 shows the batch weights of the glazes as calculated in percentages of clay, flint, and fluxes. The fluxes consist of feldspar and whiting in the proportion of 167 parts feldspar to 70 parts of whiting. As originally laid out the field consisted of the glazes numbered from 1 to 16. These were made by cross-blending numbers 1, 4, 13, and 16. A preliminary test showed that this series did not include as much of the area of bright glazes as was desired. Glazes 17 to 23 were included.

These were made by cross-blending numbers 15, 17, 21, and 23.

TABLE I

BATCH WEIGHTS OF THE CORNER GLAZES

Number	1	4	13	15	16	17	21	23
Feldspar	13.2%	14.1%	18.4%	19.6%	20.2%	20.9%	27.3%	30.0%
Whiting	5.5	9.5	7.7	8.2	8.5	8.8	11.4	12.5
Clay	26.6	15.3	36.95	27.2	21.9	16.3	37.8	23.1
Flint	54.7	64.7	36.95	45.0	49.4	54.0	23.5	34.4
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

SOURCES OF RAW MATERIALS

Feldspar—Maine Feldspar Co., Shipping point, Auburn, Maine.
Whiting —Solvay Process Co., Delray, Mich.
Clay —Edgar Plastic Kaolin Co., Shipping point, Edgar, Fla.
Flint —Penna. Pulverizing Co., Shipping point, Hancock, W. Va.

Procedure

The corner glazes already given were weighed out, and ground wet for four hours in small ball mills. The cross-blending to produce the intermediate glazes was performed by mixing the corner glazes wet in the proper proportions as determined by their relative molecular weights and specific gravities. Care was taken to obtain thorough mixing.

The glazes were applied on green porcelain discs $1^1/_4$ inches in diameter and $^1/_2$ inch thick. The discs were air dried, but were dipped in water before being dipped in the glaze. The composition of the body was as follows:

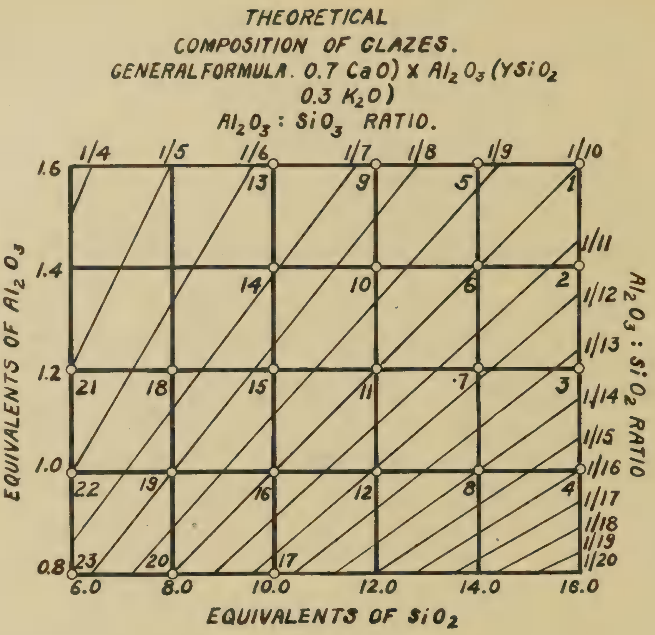

THEORETICAL
COMPOSITION OF GLAZES.
GENERAL FORMULA. 0.7 CaO) x Al2O3 (YSiO2
0.3 K2O)
Al2O3 : SiO3 RATIO.
1/4
1/5
1/6
1/7
1/8
1/9
1/10
1/11
1/12
1/13
1/14
1/15
1/16
1/17
1/18
1/19
1/20
Al2O3 : SiO2 RATIO
1.6
1.4
1.2
1.0
0.8
EQUIVALENTS OF Al2O3
6.0
8.0
10.0
12.0
14.0
16.0
EQUIVALENTS OF SiO2
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

FIG. 1.

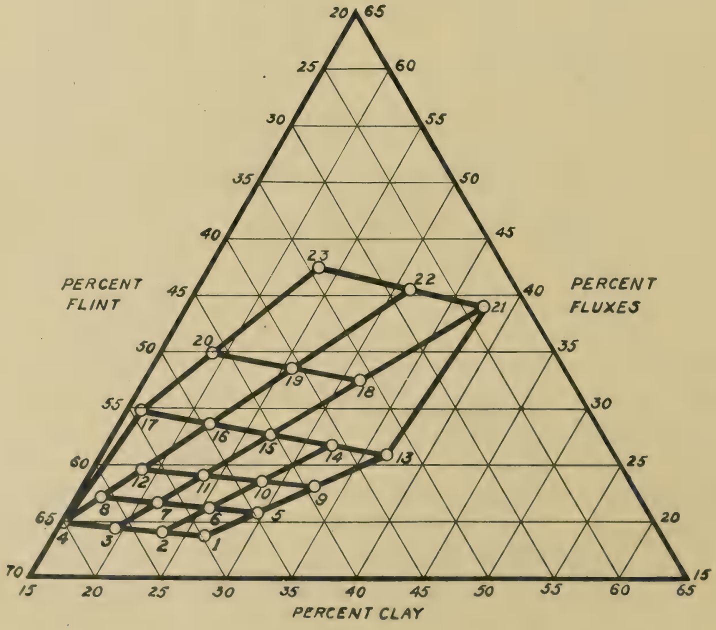

PERCENT FLINT
PERCENT FLUXES
PERCENT CLAY
20
65
25
60
30
55
35
50
40
45
45
40
50
35
55
30
60
25
65
20
70
15
15
20
25
30
35
40
45
50
55
60
65
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

FIG. 2.

English Ball Clay (M. and M.)	5.0%
North Carolina Kaolin (Harris Spruce Pine)	12.0
Florida Kaolin	8.0
English China Clay (M. W. M. No. 2)	30.0
Flint	30.0
Feldspar	15.0
	100.0%

This body was vitreous from cone 17 to cone 19, but overfired at cone 20 with a longer firing period.

In each sagger were placed three cones of proper number. Around these were arranged 23 of the discs, each coated with one of the glazes. Part of the saggers were fired in a Dressler tunnel kiln to temperatures ranging between cone $17^3/_4$ and cone 19 down. The maximum heat was reached in approximately 31 hours. Another sagger was fired in a large periodic kiln to cone 20 down. It reached this temperature in approximately 52 hours.

Results at Cone $17^3/_4$

Fine crazing occurs with a theoretical alumina: silica ratio of 1:12 or less. (Figs. 3 and 4.) This is in the region of high flint. Coarse crazing occurs with a theoretical alumina : silica ratio of 1:5 for 6 equivalents of silica. This is in the region of low flint, high clay and high fluxes. The area of smooth glazes is large. Its limits are best understood by reference to the diagrams. Between the glazes termed "Smooth Transparent" and "Smooth Opaque" there is no distinct dividing line. The opacity increases gradually in the general direction of the flint. The opaque glazes might possibly be called semi-mats, but since they become transparent when fired to a higher temperature, the term "opaque" seems more appropriate. Glaze No. 13, however, is a true aluminous mat. It has a theoretical alumina: silica ratio of 1:625 for 10 equivalents of silica. This glaze is located in the region of high clay. The glazes high in fluxes tend to be seedy due to entrapped bubbles in the glaze.

Results at Cone 18 Down

The area of fine crazing is reduced at this temperature. The theoretical alumina: silica ratio of the fine-crazed glazes is 1:14 or less. (Figs. 5 and 6.) The area of coarse crazing is increased at this temperature to include No. 22, which suffered delayed crazing after about 8 months in the air. The other characteristics are similar to those described for cone $17^3/_4$.

Results at Cone 19 Down

The area of fine crazing is similar to that at cone 18 down. (Figs. 7 and 8.) It is, however, extended enough to include No. 12 with theoretical

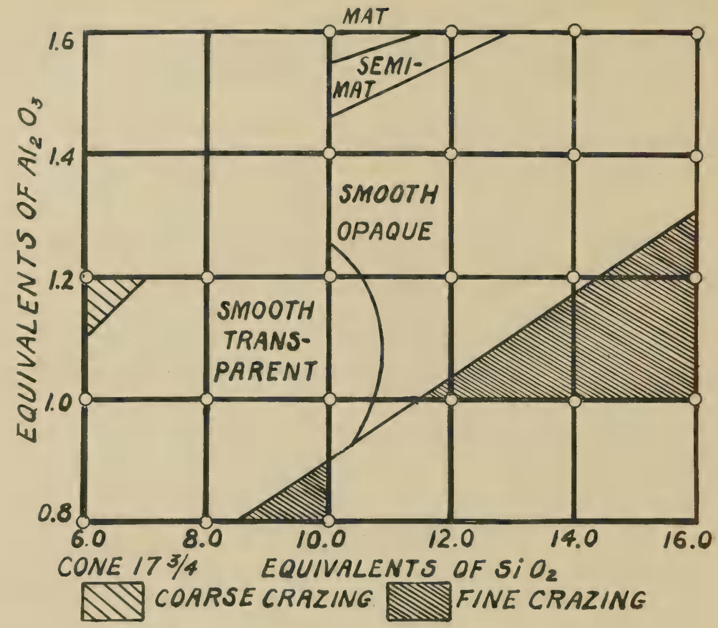

MAT
SEMI-MAT
SMOOTH OPAQUE
SMOOTH TRANS-PARENT
1.6
1.4
1.2
1.0
0.8
EQUIVALENTS OF Al_2O_3
6.0
8.0
10.0
12.0
14.0
16.0
CONE 17 3/4
EQUIVALENTS OF SiO_2
▧ COARSE CRAZING
▨ FINE CRAZING

FIG. 3.

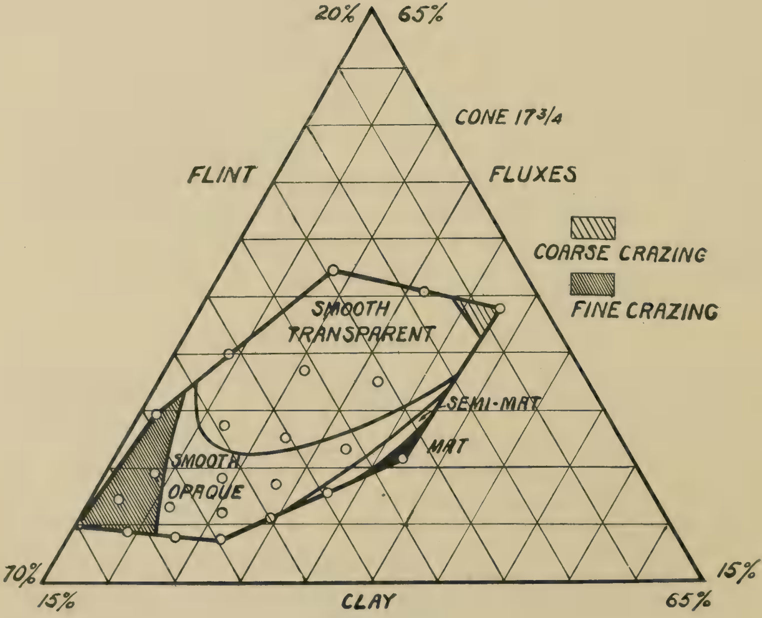

20%
65%
CONE 17 3/4
FLINT
FLUXES
▧ COARSE CRAZING
▨ FINE CRAZING
SMOOTH TRANSPARENT
SEMI-MAT
MAT
SMOOTH OPAQUE
70%
15%
15%
CLAY
65%

FIG. 4.

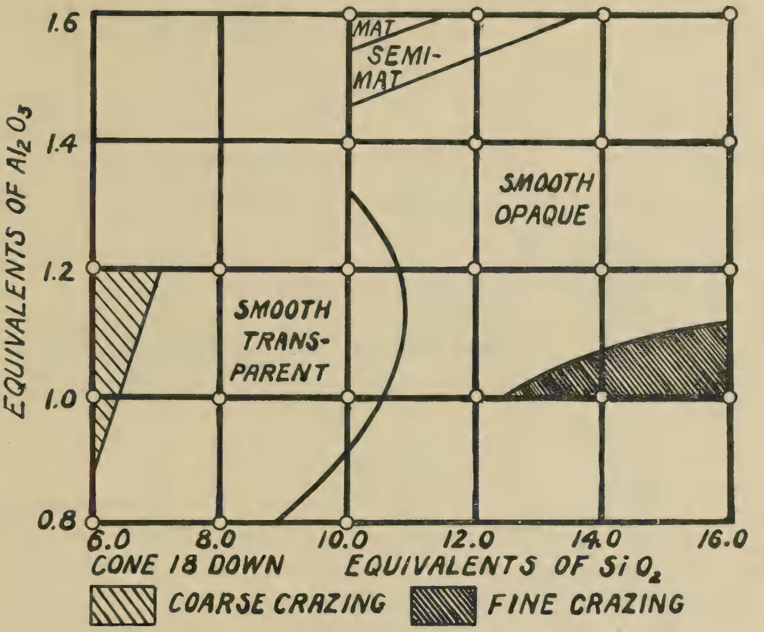

1.6
1.4
1.2
1.0
0.8
EQUIVALENTS OF Al_2O_3
MAT
SEMI-MAT
SMOOTH OPAQUE
SMOOTH TRANS-PARENT
6.0
8.0
10.0
12.0
14.0
16.0
CONE 18 DOWN
EQUIVALENTS OF SiO_2
COARSE CRAZING
FINE CRAZING

FIG. 5.

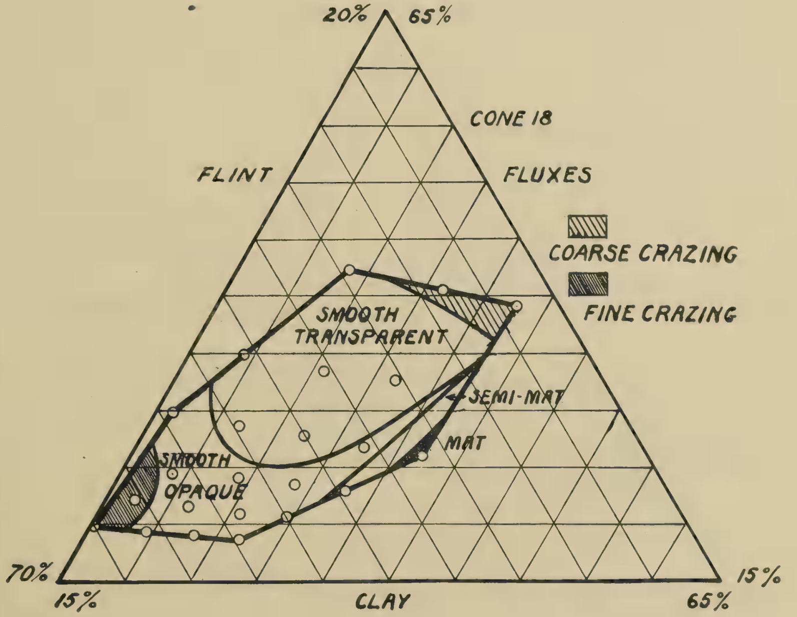
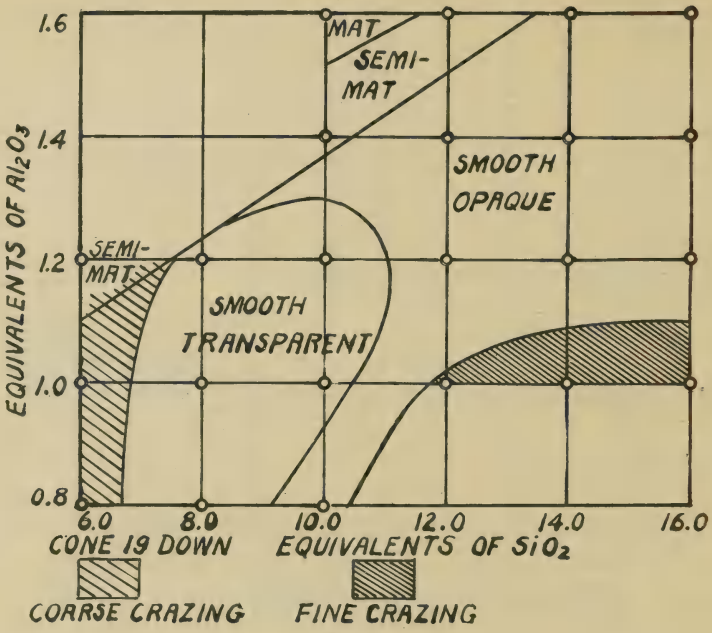
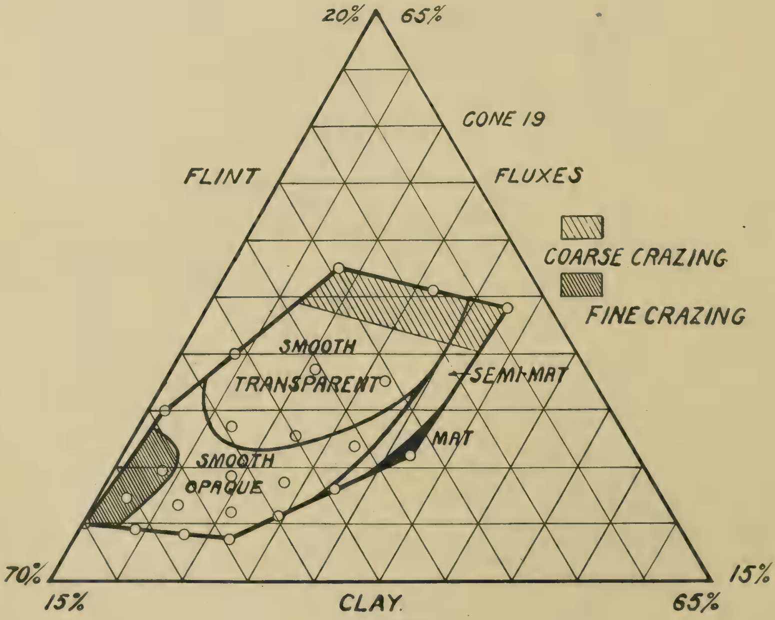

20%
65%
CONE 18
FLINT
FLUXES
COARSE CRAZING
FINE CRAZING
SMOOTH TRANSPARENT
SEMI-MAT
MAT
SMOOTH OPAQUE
70%
15%
CLAY
15%
65%

FIG. 6.



1.6
1.4
1.2
1.0
0.8
EQUIVALENTS OF Al_2O_3
MAT
SEMI-MAT
SMOOTH OPAQUE
SEMI-MAT
SMOOTH TRANSPARENT
6.0
8.0
10.0
12.0
14.0
16.0
CONE 19 DOWN
EQUIVALENTS OF SiO_2
COARSE CRAZING
FINE CRAZING

FIG. 7.



20%
65%
CONE 19
FLINT
FLUXES
COARSE CRAZING
FINE CRAZING
SMOOTH TRANSPARENT
SEMI-MAT
MAT
SMOOTH OPAQUE
70%
15%
15%
CLAY
65%

FIG. 8.

alumina: silica ratio of 1:12 for 12 equivalents of silica. The area of coarse crazing is also increased at this temperature. It includes all the glazes with 6.0 equivalents of silica. Glaze No. 23 crazed only after standing several months.

The matness of glaze No. 13 is increased, and the area of the semimats is increased to include No. 21; however, the appearance of the latter seems to indicate that its dull finish is due to overfiring. The areas which are termed "Transparent" and "Opaque" remain the same although it is hard to fix a dividing line. The transparent area seems gradually to be shifting toward the high flint region with each increase of temperature. The glazes with 6 and 8 equivalents of silica show a great deal of seediness, but this is greatly lessened with an increase to 10 equivalents of silica.

Results at Cone 20 Down

These glazes received a longer firing period than those fired to the lower temperatures. This will account for the relatively great change between the results at cone 19 down and cone 20 down. The fine crazed area has been totally eliminated. The coarse crazed area is also much decreased, only glaze No. 21 being so crazed. The glazes which were opaque at cones 17 to 19 are transparent at cone 20 down. The area of mat glazes is extended. The mats themselves tend more to roughness. The glazes of high flux content are overfired. They still remain transparent but tend to leave bare spots on the porcelain.

Conclusions

The approximate formula $Al_2O_3 = 0.3$ plus $^1/_{12}$ SiO_2, the alumina and silica being expressed in equivalents, seems to hold approximately true at these higher temperatures. This formula was given by Sortwell as the straight line axis passing through the locations of the best high gloss glazes. At cone 20 the locations of the best glazes are such that the line passing through them would tend to curve down into the region of lower alumina.

Fine crazing due to relatively high flint could be corrected by firing to a higher temperature. A better way would be to decrease the flint content. Coarse crazing in the glazes of high flux content seems to be caused or made worse by increased temperatures. This could be remedied by increasing both the flint and clay content, the latter to a lesser extent.

Mr. Sortwell reported that glazes containing over 55% of flint would not lie down to a smooth surface. The writer did not notice any such effect at cones 17 to 20. All the glazes marked "Smooth Opaque" even with high flint content were smooth glazes.

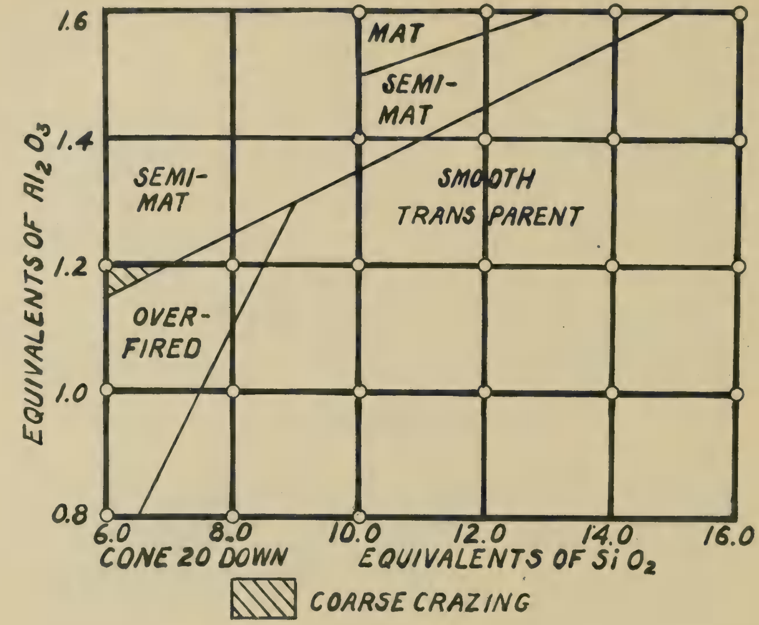

1.6
1.4
1.2
1.0
0.8
EQUIVALENTS OF Al_2O_3
MAT
SEMI-MAT
SEMI-MAT
SMOOTH TRANSPARENT
OVER-FIRED
6.0
8.0
10.0
12.0
14.0
16.0
CONE 20 DOWN
EQUIVALENTS OF SiO_2
COARSE CRAZING

FIG. 9.

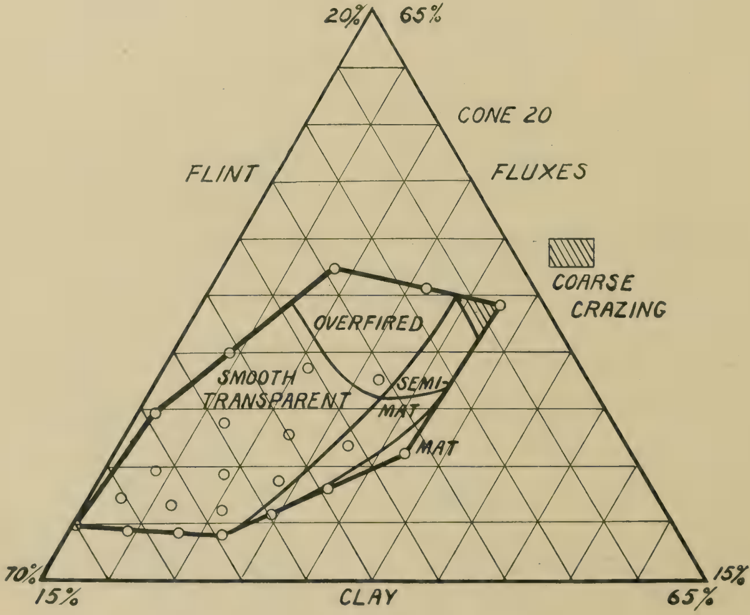

20%
65%
CONE 20
FLINT
FLUXES
COARSE CRAZING
OVERFIRED
SMOOTH TRANSPARENT
SEMI-MAT
MAT
70%
15%
15%
CLAY
65%
15%

FIG. 10.

11 2 7 5

At any one temperature there is a wide range of compositions which will give good glazes. The best glazes for temperatures to range between 17 and 20, when fired as described, are numbers 11, 15, 16 and 19. Those glazes have ranges of composition as follows:

Clay	21.9%	to 27.2%
Flint	40.8	to 51.8
Feldspar	17.2	to 23.6
Whiting	7.2	to 10.0

HIGHLAND PARK, MICH.

REDUCTION OF INDUSTRIAL WASTES[1]

By Dwight T. Farnham

Introduction

Formation of the Committee.—At the end of 1920 the Federated American Engineering Society came into being through the convening of its executive body, the American Engineering Council. On November 19th, Herbert Hoover was elected as its first President. One of his first acts was to suggest a study of wastes in industry. On November 20th a committee was appointed to make such an investigation. On January 12th, 1921, Mr. Hoover named fifteen engineers as the Committee on Elimination of Waste in Industry. The report was issued and signed by:

J. Parke Channing, *Chairman*
L. W. Wallace, *Vice-Chairman*
L. P. Alford,
Geo. D. Babcock,
Wm. Bassett,
F. G. Coburn,
Morris L. Cooke,
Harrington Emerson,
Ira N. Hollis,
Herbert Hoover,
Robert Hinton,
E. E. Hunt,
C. E. Knoeppel,
F. J. Miller,
H. V. R. Schell,
Sanford E. Thompson,
John H. Williams,
Robert B. Wolfe.

From April 1st to May 13th the reports were submitted. On July 15th the reports were approved by the Committee. It may be historically interesting to know that this Committee met in St. Louis, and the discussion as to what should go into the report and what should not go into the report started here. It is a very wonderful piece of work. The complete report is given in a volume entitled "Waste in Industry" which can be obtained from McGraw-Hill Book Company. The report is very much worth reading, because it contains data which is impossible to be given in a paper such as this. It is a great deal like some of the ceramic papers. You want to go home and take some black coffee and put some ice on your head and get down to business, to get the real meat out of them. The meat is there when once you concentrate on them.

Plan of Investigation

The investigation was based on a questionnaire. This was used to investigate all the industries, so the committee would not have a mass of data which was not correlated in any way, and so that the final result might represent the same sort of investigation in each industry. Connected with this questionnaire was a valuation sheet on which a rating was given to the different industries by the percentage system. Of course, an industry couldn't be one hundred per cent waste, and it was necessary to decide what should constitute waste, and how many black marks should be given in each case. Eventually, complete reports were made on men's clothing, the building industry, printing, boot and shoe manufacturers, metal trades, and textile factories. It was found that waste was attributable to *low production*, caused by faulty management of materials, plant equipment and men; *interrupted production*, caused by idle men, idle materials, idle plants and idle equipment; *restricted production* meaning production intentionally restricted by the owners and by managers, or by labor; *lost production*, caused by ill health, physical defects and industrial accidents.

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[1] Address given at the St. Louis Meeting, February, 1922.

The conditions in the different industries can perhaps be best gauged from the following table:

	Points assigned against		Responsibility assigned against		
Industry	Best	Average	Management	Labor	Public, etc.
Men's Clothing	26	63	75%	16	9
Building	30	53	65	21	14
Printing	30	57	63	18	9
Boots & Shoes	12	40	73	11	16
Metal	6	28	81	9	10
Textile	28	49	50	10	40
Total			Over 50%	Less than 25%	

The committee, after some debating, decided that at least fifty per cent of the waste in industry in general was attributable to management, and less than twenty-five per cent to labor.

The causes of low production caused by *faulty management* were due in these various industries to such things as:

1. **Faulty Material Control.**—They found, for instance, in certain shoe factories, that operatives were waiting for materials, and for orders for work about thirty-five per cent of the time. These figures that I am giving you are not caused by seasonal demands or the reverse, but delays occur when there are plenty of orders in but workmen are not able to go ahead because the tools are not ready or production orders are not ready, or conditions are unbalanced in the plant—they may have one part of the finished product but not another.

2. **Faulty Design Control.**—For instance, the Federal Bank check cannot be cut from any regular paper size. The variance in the size of newspapers, magazines, and so forth, costs the public over one hundred million dollars a year. The standardization of newspaper columns would save from three to five millions in composition and plates alone.

3. **Faulty Production Control.**—That is, lack of planning the work. In one plant the waste took up one-fifth of the workers' time in this way. Loss in clothing factories runs to thirty or thirty-five per cent. The engi-

neers figure about three-quarters of a million dollars a day could be saved by properly planning the work in the clothing industry in the United States alone.

4. Lack of Cost Control.—It is surprising how many companies have no idea what their goods cost them. In printing concerns that were looked over, fifty-six used a standardized cost system, one hundred and eighty-seven plants knew something about their costs, seven hundred and forty-one had no cost system, but had a little knowledge as to what their work was costing them, five hundred and fifty-four had no cost system and no knowledge. As a result of that, during 1919, the first two groups only made money, which is pretty good proof that a cost system is needed in a plant if it is to be run intelligently and for profit.

5. Lack of Research.—I don't need to tell anything about the necessity for that—research is what most of us here know from the ground up.

6. Faulty Labor Control.—Very few people analyze the reasons why men quit. Whenever a man quits it is necessary to break in a new man at a cost of anywhere from twenty-five to two or three hundred dollars. Various abuses occur in the usual plant which would not occur if the "quits" were analyzed and the manager knew which foremen were losing their men, and why. I have found foremen who had a turnover of one thousand per cent a year. High labor turnover can usually be reduced if certain departments can be shown how to handle their labor or some other difficulties done away with, such as those which come from inadequate rate setting.

7. Ineffective Workmanship and Faulty Sales Policy.

Study of Wastes Due to Interrupted Production

1. Intermittent Employment causes loss which has resulted in a great many idle men in certain industries. In the clothing industry, the workers are idle about thirty-one per cent of the time; shoe workers about thirty-five per cent of the time; and the building workers, thirty-seven per cent of the time.

2. Idle Material is exceedingly wasteful because of the fact that when you get a lot of money tied up in material, more material than you need, you have to pay interest on that money. That is the trouble a lot of people have been getting into the last few months. Industries have had thousands of dollars tied up in materials, and when the value of the materials dropped the business has had to take a two or three hundred thousand dollar loss. One concern recently went into the matter of the materials they had on hand, and found there was $250,000 worth of tool steel that they did not know they had. Another had about $300,000 worth of fire brick that did not appear anywhere on their books. Of course, that is not a bad thing for the brick business, but it is pretty hard on owners at a time when they can't get money at the bank.

3. Idle Plants.—American industry is very much overbuilt. Of course you realize that in the clay business. The clothing factories are about forty-five per cent overbuilt; printing plants over fifty; and the shoe industry over fifty per cent.

Under Restricted Production Wastes

1. Closing of Plants.—The owners get together and shut down plants to shut out labor and decrease production, with the idea of getting prices up.

2. Restricted Output by Labor.—We are all familiar with the joke about the union plumber who always comes without his tools and then sends his helper back for them. Of course, systematic soldering on a large scale was due recently largely to the fact that during the war labor had things more or less in their own hands. Nobody does any more work than they have to in this world, and when there were two jobs for one man nobody did hardly any work at all, because they could go across the street and get a job which was probably better and easier.

3. Wastes Due to Ill Health of Workmen.—The economic loss from preventable disease is estimated at one billion dollars a year. The economic loss in 1919 alone from industrial accidents amounted to $853,000,000.

The remedies for the wastes we have enumerated are to a large degree disclosed by the statement of the wastes themselves. Of course, in the first place, more effective management is demanded. I am not going into that because we have plenty of literature on effective management. Since 1910 the market has been flooded with books on how to run your business, all the way from building your factory up through sales and financing. That of course is the result of the demand for more exact methods of management.

Co-operation of Labor Required

Standards of work were recommended by the Committee. It is a rather curious thing that we should pay a workman, as we do under the day work system, an exact amount of money which is measurable and then not measure the work which he does for that amount of money. If you turn the thing around the other way, and say to labor, "We will expect you to do a definite amount of work, and we will give you a piece of money," and then not specify the size of the piece of money, we would have a terrible howl from labor. Yet today labor says: "You give five dollars a day, and I will give you an indefinite amount of work" and manufacturers have been standing for it. It is a ridiculous situation.

To get away from this sort of thing piece rates were invented. The difficulty with this has been that up until the last few years, piece rates were set very largely by bargaining. A man would say, "I think I can make five boxes a day," and the boss would say, "You are crazy, you ought to make ten," and they would fight it out until finally the man would say, "Well, I will make seven," and seven it would be; when, as a matter of fact he could make fifteen if everything possible were done by the management to help him.

Scientific Standards of Labor

In the garment industry in Cleveland, about two years ago the labor unions put up half the money, while the manufacturers put up the other half of the money, to engage a firm of industrial engineers to set standards as to how many garments should be made by one person per day. I was told in England last year by a labor leader that there would undoubtedly be no objection to scientific management in the plants of England, if labor paid for the work.

This matter of co-operation between labor and capital is discussed a good deal. Their interests of course are different. Labor wants to get all it can, and the boss wants to get the work done as cheaply as possible. I feel that Secretary of Labor Wilson's analysis of the thing is the real way to work it out—labor to produce all it can, and then after the production has occurred, to sit down at a table and figure it out as scientifically as possible with the employer, as to what share should go to labor and what to capital. It is needless to say if nobody produces anything there is nothing to divide. The need of public interest in such matters is very great.

One of the things that gave the Committee a good deal of publicity was their recommendation that there be fewer style changes. I think the turnover in women's garments is three and a half a year, and in men's clothes two and a half times a year. That means men buy one suit for winter, and another suit for summer, and that there are enough dudes that buy spring and fall suits to make up the other half turnover. The women are more stylish and they buy a winter suit, a summer suit, and a spring suit, and half a fall suit. That sort of business is terribly expensive, as you who are married know. What we really ought to learn in America, is to buy on a basis of *cost per year;* I had luncheon this noon with a man who is a good deal of a student of affairs. He showed me a pair of shoes he had on, and said that he had paid $6.00 for them five years ago. That figures a little over a dollar per year. I don't know how many people figure their shoes that way, but such things should be figured. It is quite common to see in advertisements in English periodicals a letter something like this: "I am returning herewith the rainproof coat bought from you fifteen years ago to be re-proofed." None of us do that sort of thing in this country. Try, for instance, to get your wife to buy a durable hat, and see what happens. Cost to the consumer per year is a slogan that has already been adopted by the Building Brick people.

Trade associations can do a great deal of good, and the necessity for standardization hardly needs discussion. National statistical service is necessary. There are so many manufacturers that are rushing things to the same market, "carrying coals to Newcastle," without a real knowledge of where the things are needed, and of where the market is flooded.

Principles of adjustment for labor disputes should be laid down. There is something that the Government has attempted from time to time but the condition in this country is that labor unions are so new and so much disliked by the employers that as soon as union labor and the employer get together there is immediately a fight. Judge Taft said at the University Club in St. Louis, that when he was sitting on the Labor Board during the war, they couldn't accomplish anything during the first three months because labor and capital spent all of that time telling the Board the dirty tricks the other side had been playing on them. Abroad they have been through the fight longer, and unions know what they can expect to get. However, even when they have brought in a new union like the Clerks' Union, they have about what we have in this country, because the newly made union man thinks he ought to ride in the limousine and the boss ought to walk, and until he finds out the relation of things in general he has rather a bad time of it.

Necessity for a public health policy goes without saying, and industrial rehabilitation work is very necessary. Certain industries have been employing the blind and the deaf and dumb, and it is surprising the number of people who are defective who can be used in certain sorts of work.

Necessity of Elimination of Waste

There is a certain pleasure in being wasteful and inefficient We are all familiar with the oil-county Johnny who goes down to New York and lights cigarettes with twenty dollar bills. There seems to be a sort of satisfaction in waste for certain people, but it is something we cannot afford. The statement is made in the study of waste in industry that American industry, as a whole, is much more efficient than European industry. That may be so, but at the same time we gave away during the war all the best methods in America, when they were put at the service of European industries. An Englishman who had dinner with me the other night who had been in contact with the firing line of the sales forces of the biggest industries of all Europe, said that every nation in Europe was getting ready for the race for world's trade; that they were like a lot of racers on the track waiting for the pistol to go off, but that singularly enough America didn't seem to know there was a race on at all. The necessity for getting ready for world competition is that you have to ship goods abroad, or else there is a kind of competition that is very damaging to industry with plants working at part capacity. The best information I have been able to get on the subject is that ten per cent of our products must be shipped abroad if our plants are to be kept busy.

In competing with European labor, there are two things to be considered. One of them is the efficiency of European labor, and the other is what it is paid. I will quote some figures, to give you an idea of what the situation was in 1920. The United States was paying a first-class machinist $45.00 a week; England was paying the same man $14.70 a week; France, $8.31 a week; Italy, $5.47 a week; and Germany was paying him $4.68 a week. The men in the plants that I went through in the United States were running from four to six automatics a piece, in England one to three, in France two to three, in Italy one to two, and in Germany from three to four. Now, even if we are twice as efficient as they are over there, the pay in the United States is three to nine times as much; so we cannot afford these wastes. I had dinner with a banker in New York not long ago, and he said one of our large cable companies wanted a cable laying ship. The bid in the United States on this ship was $900,000; the French bid was about $850,000; the British bid was slightly over a million; and the German bid was $350,000.

Standardization of Materials

Now, in your own industry there are great savings that can be made by the standardization of materials. To too many of the older type of manufacturers, clay is clay. Most of you have been troubled with the farmer coming in with everything from chalk to flour, and telling you it is kaolin. So it has been with a good many of the manufacturers: they have not tested and standardized their materials as carefully as they should. Of course, some of the manufacturers have. I know one paving manufacturer, for instance, who keeps track of the particular part of the bank that the shale comes from. At one plant they had an argument as to how much sand should go into the brick, and they did nothing but argue it for two or three years, and then somebody got a bright idea and they made up brick containing no sand up to sixty or seventy per cent. Eventually they found thirty per cent sand was the best. That killed the argument.

Mechanical handling in many of the plants is very much underdone. This is especially true of the raw materials. I remember about ten years ago going to see the last word in sewer pipe factories. I was told I would see all the latest improvements. I traveled a thousand miles to see this plant and the first thing I saw was six men each in a gondola car, shoveling clay out over the fence. About twelve more colored gentlemen were shoveling it up and wheeling it to the dry pans. That was what I had gone a thousand miles to see!

As far as I know, nobody has gotten down to brass tacks as to the correct size of kiln flues for the heavy sorts of clay ware. There have been a good many articles on the sizes that *are* used, but no one has really gone into the scientific principles of the thing. I tried it once, and made a rather poor job of it, and since that time there have been arguments as to what is a good kiln; but what really is the most effective size of the flue, has not to my knowledge been finally settled.

I hired a ceramic engineer once and his first job was to take a miner's lamp and go through all the flues. Later on after we got the top coat off these flues we couldn't see how a man that weighed a hundred pounds could have possibly gone through them. The standardization of kiln flues is absolutely necessary if you are to burn your product as quickly as possible with the least amount of coal.

The output of a plant is very often interfered with by changing equipment in the midst of production because there is not enough of the right sort of clay in the bins, because of break downs or for some other reason connected with planning the work ahead. All this means men standing around and increased costs.

Technical Control

Technical control is of course very necessary. I think people are pretty well sold on pyrometers now, but a great many have not taken the next step, that of making it worth while to the men who are handling the kiln to work to the best advantage. When kiln bottoms are standardized you can set up a burning schedule that can be adhered to from hour to hour. Once this is done the firemen can be paid on the basis of quality of product, on the basis of coal saved and on the basis of labor saved. Where you have their interest tied in, you will find wops who cannot speak English using technical instruments in ways that are almost unbelievable until you have tried it.

A good deal can be said about cost system. I remember one cost system devised for the clay business by an expert accountant who had a bright idea. He said, "Count only the spoiled stuff from the kiln; don't bother to count all the stuff, and you will save a lot of time." Inasmuch as the men who set the kilns are generally paid on a basis of how much tonnage they put in, and the men who draw the kilns are paid on the same basis, it was to the interest of both to boost the figures. Since they get blamed if they break anything, they don't report much breakage. The result was the kilns were always running from ninety-nine to a hundred and one per cent good wherever this system was put in. It is necessary to know something about the clay business and about management if you are to get anywhere with a cost system.

Organization is largely a matter of managing so everybody knows just what he is responsible for. I have found as many as five different men giving orders to the Maintenance Department in a clay plant. In such a case the Maintenance Department did the work of the fellow who had the biggest pull or who made himself most disagreeable, regardless of the necessity for the particular piece of work. The organization of a good many clay plants reminds me a good deal of a statement made by the manager of a Sheffield plant who said they drew up an organization chart showing the lines of authority, and there were so many lines all of which represented men giving orders to the same men—that they tore the whole thing up.

Administrative Control

Finally, we have what is known as administrative control, the method of determination of the policy by which to run the business. In every business there is one man who is an administrator. He is the man who makes up his mind it is a good thing to cut labor or raise wages, and that sort of thing. He, having made up his mind as to what policy should be carried out, tells the executive to go ahead. The executive's job is to deal with men—to get them to do as efficiently as possible what they should do. Administrative control deals with budgeting expenditures, financial forecasting and the like. You will find it fully explained in the May issue of *Administration* published by the Ronald Press of New York.

The annual saving due to the elimination of waste in one clay plant was as follows: on raw material handling was $8,000; on grinding and tempering $6300; and in the machine room $15,000. Machine break downs were reduced 58%. The saving in burning amounted to $14,355; the saving of coal was $39,392. Production was increased 48%. Demurrage reduced 68%. The excess men used were reduced from fifty to twenty-nine per day. Labor turnover was reduced 55%. Complete costs were furnished on the seventh of the month instead of the eighteenth to the thirtieth. Altogether the total annual saving amounted to something like $180,000 a year without counting the profit on the increased output. That sort of thing is worth considering.

I have attempted to give you a little idea of the systematic work that has been done by the Committee on Waste in Industry. My feeling is that the members of the American Ceramic Society are in a position to do more to eliminate waste in their own industry than any one else. What happens will rest very largely on how much the members of this Society interest themselves in the economic and financial aspects of the business. Gentlemen, it is up to you.

C. E. Knoepple and Co.
New York City

USE OF FORCED DRAFT FOR TERRA COTTA KILNS[1]

By John L. Carruthers

ABSTRACT

Application of forced draft system to terra cotta kilns is described. Special features are (1) type of grate used, (2) overhead air flues, and (3) use of cheap slack coal.

Advantages over natural draft system formerly used are (1) a net saving of about 20% in burning costs, (2) better control of combustion gases and kiln temperatures, and (3) uses less skilled labor for firing.

The purpose of this paper is to give a description of a forced draft system that has been successfully applied to periodic muffle kilns such as are used for firing architectural terra cotta. Incidentally, this system has been applied to round down-draft brick kilns, with very good results. No attempt is made to discuss the advantages or disadvantages of forced draft as compared with either natural or mechanically induced draft.

The terra cotta kilns on which the forced draft system has been installed are of the up-draft and down-draft muffle type, varying in size from 9 to 23 feet in diameter. No changes have been made in the design of the kilns in applying this system.

Formerly a combination inclined and horizontal grate bar furnace was used. The new grates are placed at the level of the old horizontal bars. The old fire and ash door openings have been changed to meet the requirements of the new fire door, and this is the only change made in the structure of the kiln.

The principal feature of the new system is the grate, which consists of a $^3/_{16}''$ sheet iron box and a cast iron plate, typical details being shown in Fig. 1. All joints of the box are welded. The grate plate is made in two pieces, with a ship lap at the joint. Doing this, allows a cracked or burned end of a plate to be replaced without using an entire new plate. The life of the front half of the grate plate is generally longer because part of it acts as a coking table and is not subjected to the intense heat of the rear of the furnace. The cone-shaped part of the air holes is provided in the casting, the remainder of each hole being drilled to the size needed for the particular kiln in which the plates are to be used. The weight of the plate and the style of joint between the box and plate are sufficient to hold the latter in place and to prevent appreciable air leakage at the joint. The air passing under and through the plates keeps them relatively cool and thus lengthens their life. With a few exceptions, the original plates installed eighteen months ago are still in good condition and from all appearances will last for some time.

The grate box is connected to the air flues by a 4-inch tee and nipple, the latter being welded to the box (Fig. 2). The little ash that falls through the air holes into the grate box is raked out through the tee. The plug in the tee should be taken out in case the blower is stopped while the kiln is under fire or when firing is finished. If this is not done, an explosion may take place in the grate boxes and the air flues. Such an explosion is caused by the ignition of unburned gases that are pulled into the grate box and flues by a back draft that is created with an overhead flue system when the air pressure has been eliminated. Closing the draft valves checks this back draft and removing the plugs allows a natural draft of low intensity, due to small grate openings, to be created. This procedure eliminates the danger of an explosion and also keeps the grate plates from getting too hot.

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[1] Read before Terra Cotta Division, St. Louis Meeting, February 28, 1922.

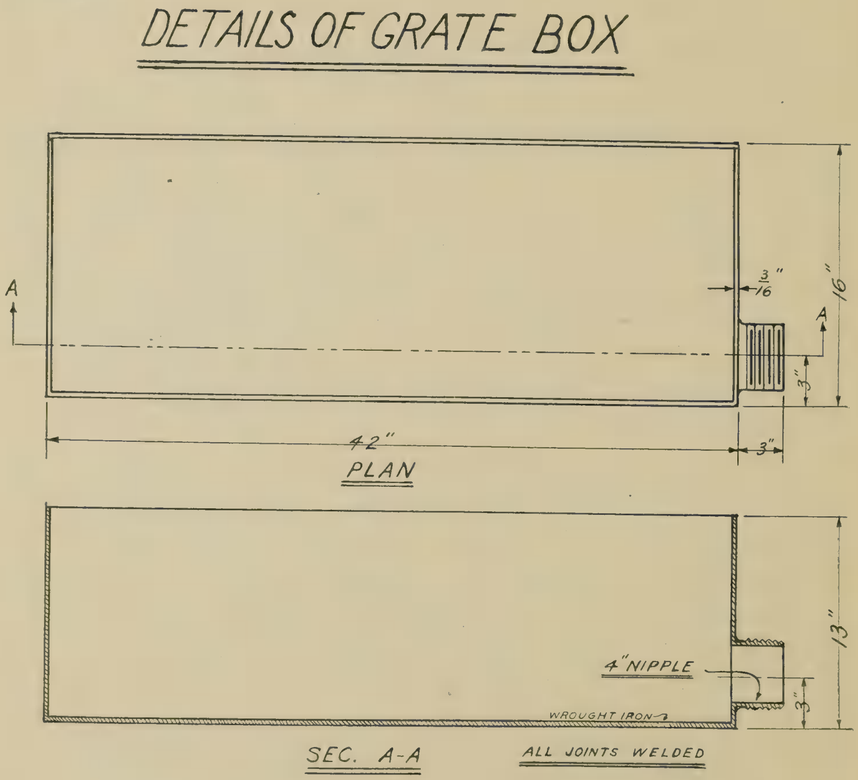

FIG. 1.

Fig. 2 also shows the type of door used and the method of hanging it on the kiln. The door is a thin cast iron box in which is placed a fire clay slab, held in place by means of set screws through the top and one side of the casting. This method of securing the slab in the frame eliminates cracks that would occur if bolts were put through the face of the slab. In case the slab does crack, the set screws can be tightened and the pieces will remain in place.

The draft is furnished by a No. 6 volume blower driven by a 5 H.P. motor. The intensity of the draft is controlled by a gate valve in the air pipe to each grate. Thickness of the fuel bed is also used to regulate burning conditions.

Fig. 3 shows a typical installation of the overhead air flue system on two of the kilns. The flues are made of 22 ga. galvanized iron. All joints were crimped, wrapped with cloth, and a coat of shellac applied to make them air tight. In the installation shown, the motor and blower are above the kilns. For the other kilns, a blower and motor are mounted on a platform and transferred from kiln to kiln as needed by means of a jacklift truck. Electrical connections are provided at each kiln. The use of small units requires less power than if a central blower house was maintained. Long flue systems with loss of draft due to excessive friction, and half

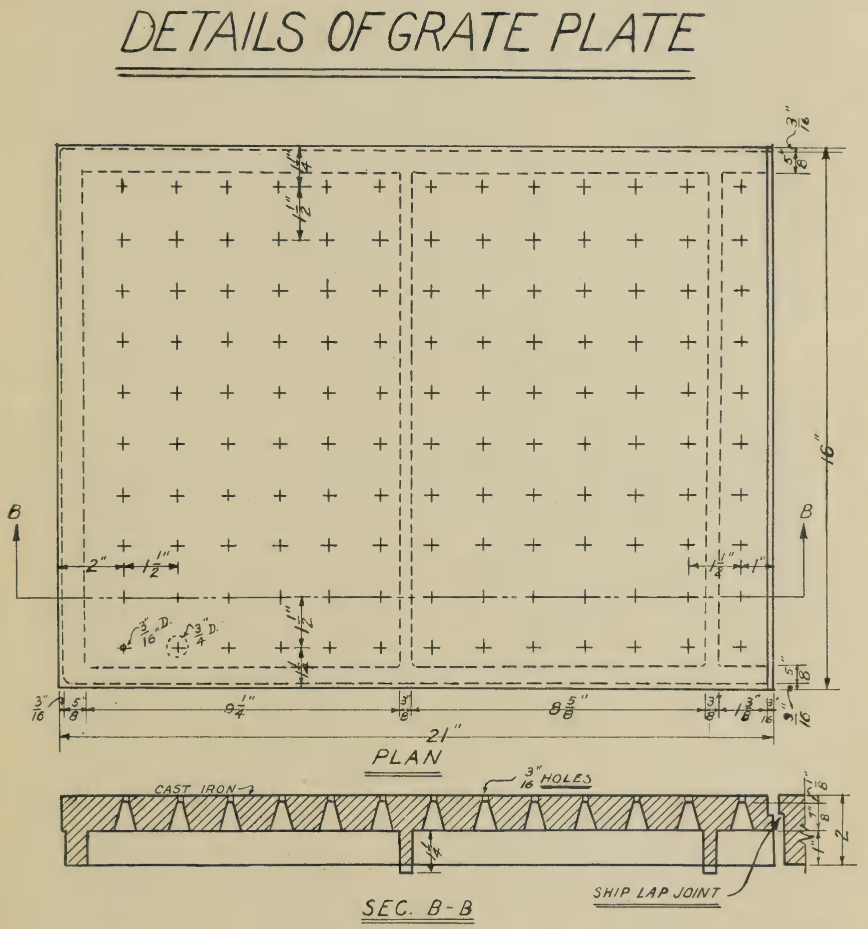

FIG. 1a.

loaded blower equipment, that would occur at times, are eliminated. Placing the air flues above ground has eliminated the troubles ordinarily found with underground flues, such as water, and leaks that are hard to locate. The overhead system is less expensive to install than an underground one and can be more readily repaired should leaks occur.

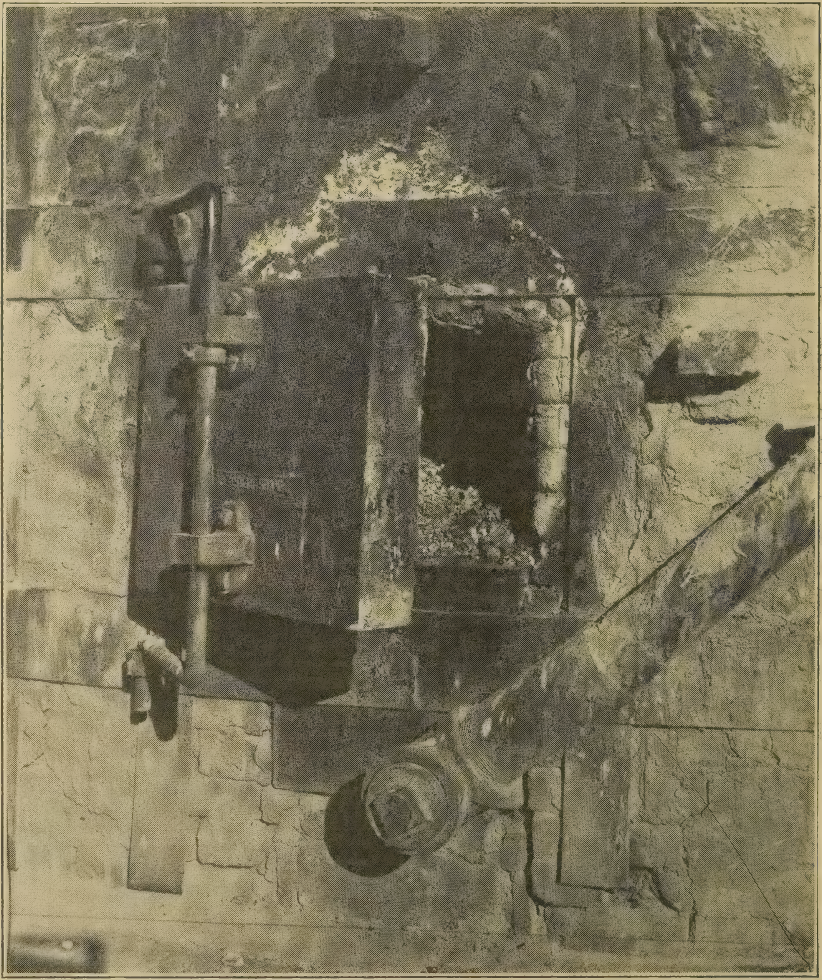

Fig. 2.

With the old type of furnace, a certain high grade of bituminous lump coal was necessary to secure good results from the firing operation. This coal had to be forked before using, the resultant slack being used as boiler coal in place of cheap lignite slack, thus increasing the cost of kiln and boiler firing. Practically all grades of bituminous slack coal have been successfully used with the forced draft system. Slack coal has a much

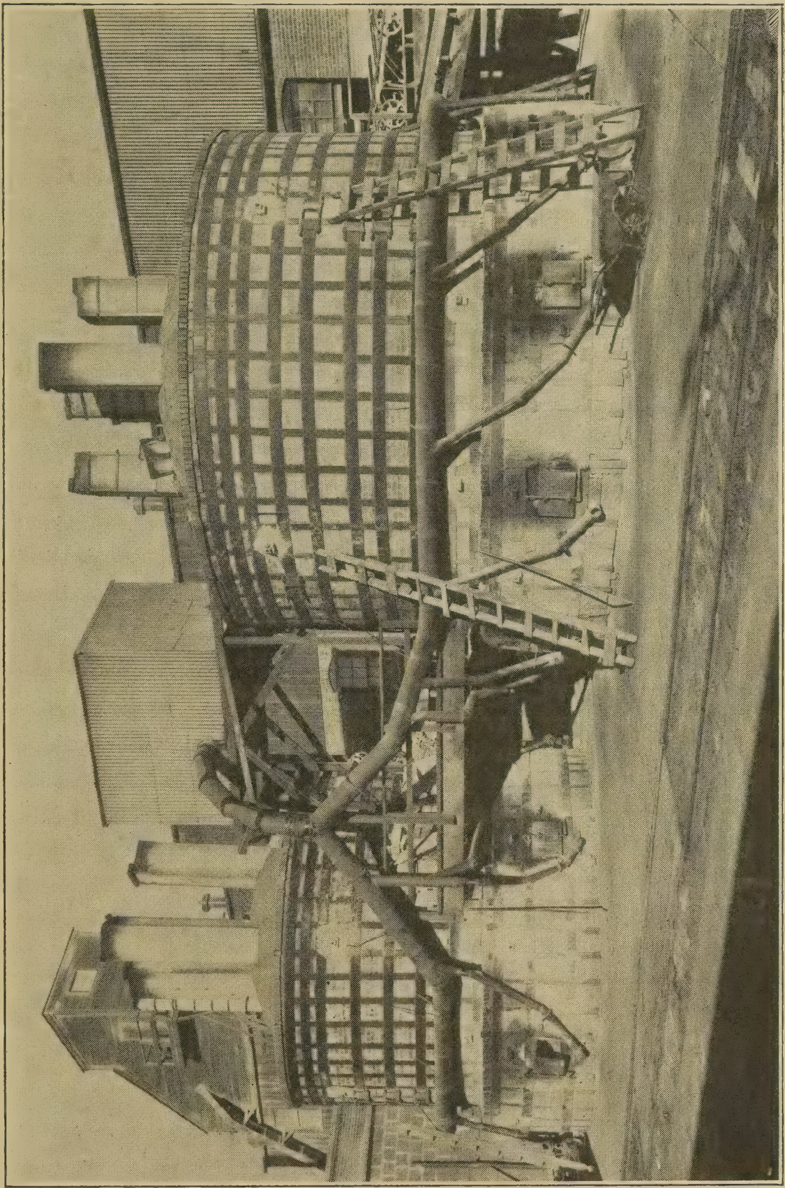

FIG. 3.

lower mine price, lower freight rate, costs less to handle and store, and makes the labor of kiln firing easier, when compared with lump coal.

For several reasons, it was considered advisable to lengthen the firing period about the time of the installation of the forced draft system, consequently the amount of coal per kiln or ton of ware has been somewhat increased. However, the firing period and coal consumption could be reduced with forced draft and still obtain a reasonable amount of good ware. Considering the initial cost of the coal, freight, handling, storing, and increased fuel consumption, the use of slack coal by means of the forced draft has cut the fuel bill almost in half, tonnage of ware being the same.

Forced draft has reduced the amount of ash, unburned fuel, and clinkers which were found with the natural draft system. Very little clinker is found along the walls because of the thin fuel bed maintained, with a consequent increase in the life of the furnace lining. Due to the high temperature in the furnace and the fine ash blown from the fuel bed by the forced draft, the walls are coated with a slag. This slag has formed a smooth coat over the furnace lining and the lower parts of the muffle. Observation to date shows that this slag coat has had little effect upon the life of the furnace or muffle linings.

The forced draft system has made it much easier to maintain even temperatures in all parts of the kiln during the firing period. The type of labor required for firing does not have to be of the same high class that was necessary when using natural draft, hence the relative cost of labor per hour has been reduced. A fairly thin fuel bed is maintained to secure the best results, which necessitates more frequent firing. The labor of firing has been made easier, though more constant, by using slack coal.

The costs of this system, excluding installation, not found when natural draft was used, are power, maintenance, and depreciation of mechanical equipment, and an increase in the total labor cost due to the lengthening of the firing period. These are more than offset by the saving in the fuel so that a net saving of about 20 per cent, in the burning costs has been secured through the replacement of natural draft by forced draft.

Denver Terra Cotta Co.
Denver, Colo.

STABILITY AND DESIGN OF A KILN STACK

By T. W. Garve[1]

ABSTRACT

Introduction.—It points out the advantages and disadvantages of stack draft compared with fan draft and the necessary calculations for stability. It discusses the merits of the various cross-sections and the difference in stability of round, octagon and square stacks. (Fig. 1.)

Theoretical Consideration.—Calculations on dead weight and wind pressure are made on an average sized periodic kiln stack and the conclusion is reached that it is necessary to figure each stack section as a beam, fastened to one end, for compression and tension. (Figs. 2, 3, 4, 5.)

Practical Requirements.—A number of essential practical pointers are given for designing or building stacks, all fully illustrated in Figs. 6, 7, 8, 9.

Introduction

The advantages and disadvantages of a stack compared with a fan are as follows:

Advantages:

1. Draft always available, not depending upon any source of generated power.
2. Practically no upkeep.
3. No power consumption, wear and tear.
4. Needs hardly any attention, hence saving of labor.
5. No danger of overheating.
6. No destruction in case of fire.

Disadvantages:

1. Influenced by weather.
2. Draft limitations and limitations of control to a certain extent.
3. Exposed to the destructive elements of nature.

Fans are usually connected to continuous kilns and stacks to periodic kilns.

A proper kiln stack should answer theoretical considerations and fulfill practical requirements, yet there are many kiln stacks in existence which answer neither condition.

As regards draft conditions and temperature, size and height of stack, we refer to Lovejoy's "Burning Clay Wares."[2]

However, a stack also must be strong enough to withstand all destructive agencies, yet not so heavy that material and money are wasted.

A stack must: First, carry its own weight, and foundation and soil must safely carry the weight of the whole stack. Second, the wind pressure, acting upon the bottom of the stack column, foundation and soil, must safely be withstood. Third, the stack column itself in its varying cross-sections must be safe against breaking due to wind pressure.

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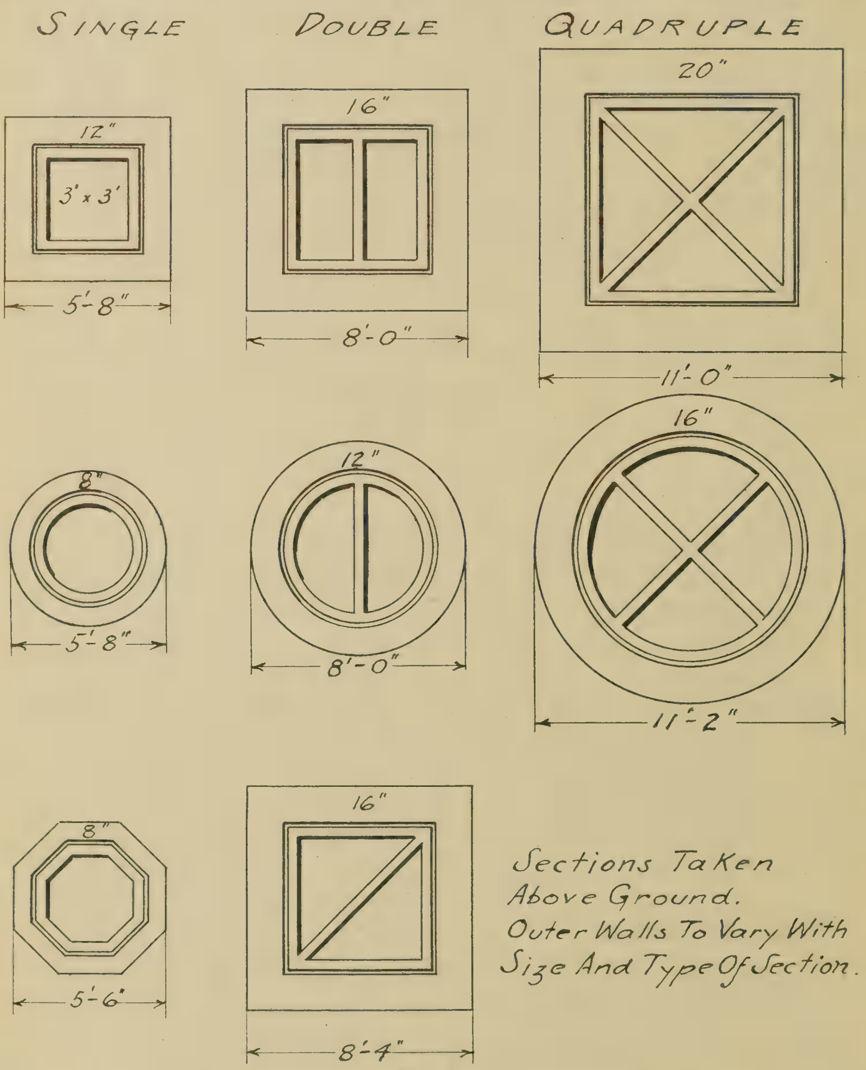
[1] Read before the Heavy Clay Products Division, St. Louis Meeting, Feb. 28, 1922.

[2] T. A. Randall & Co., Publishers, 1920.

Stacks are built square, circular, and octagon, but kiln stacks are usually built square. Kiln stacks are built single, double and quadruple. A



Sections Taken Above Ground.
Outer Walls To Vary With Size And Type Of Section.

FIG. 1.

quadruple stack, of course, is cheaper than four single stacks, but it is necessary to carry the partition to the top of the stack. The cross-section of each stack flue (see Fig. 1), whether a square or a rectangle or a triangle or a circle or a semi-circle or a segment or an octagon, must correspond to the size of the outlet required to carry out the gases, taking into consideration the friction of the gases along the sides varying with the shape of the flue and the length of its circumference.

The most economical cross-section is the circle, being shorter than the square, rectangle, triangle, or any other figure to circumscribe the same area. In addition to this, there is a greater frictional loss at the corners of a square and rectangle and especially triangle, hence these cross-sections must be made correspondingly larger in order to receive the same pull. The square cross-section comes next to the circular, and most kiln stacks are square.

Referring to the elevation of the stack column, a square stack offers a greater surface of resistance to the wind than a circular stack, hence should be made correspondingly stronger. If we call the effective wind surface of a square stack 100 per cent, the effective wind surface of an octagon stack will be 70 per cent and of a circular stack 67 per cent, which is about two thirds of a square stack. Hence if we assume in our calculations a wind pressure of 30 pounds per square foot for a square stack, we need to figure but 20 pounds for a circular stack in reference to the projected area exposed to the wind.

Theoretical Considerations

1. Safety against Crushing of Bottom Course, Concrete and Soil.—For our theoretical considerations let us assume an average stack as shown in Fig. 2.

The total weight of the brickwork (without the lining) figures 96,000 pounds. The cross-section of the botton course of brick measures 28.75 square feet, which will give a pressure of 3340 pounds per square foot, an amount very far below the allowable compression of brickwork and concrete.

The crushing strength of good brickwork with proper mortar and also of concrete is in the neighborhood of 3000 pounds per square inch, or an allowable safe load of 600 pounds per square inch (with a factor of safety of five), equal to a safe load of about 86,000 pounds per square foot.

Of course, the concrete slab should be heavy enough to distribute the weight over the soil without cracking or breaking. A two foot slab is heavy enough for any ordinary single or double kiln stack.

Upon the soil below the concrete slab we have a total weight (stack plus lining plus slab) of about 136,000 pounds or 68 tons.

Since the concrete slab measures 56 square feet, the above weight will exert a pressure of 1.2 tons per square foot which is safe for any soil. The allowable bearing values of soils from clay to rock vary from 2 tons to 20 tons per square foot; these values can be found in any engineering hand book.

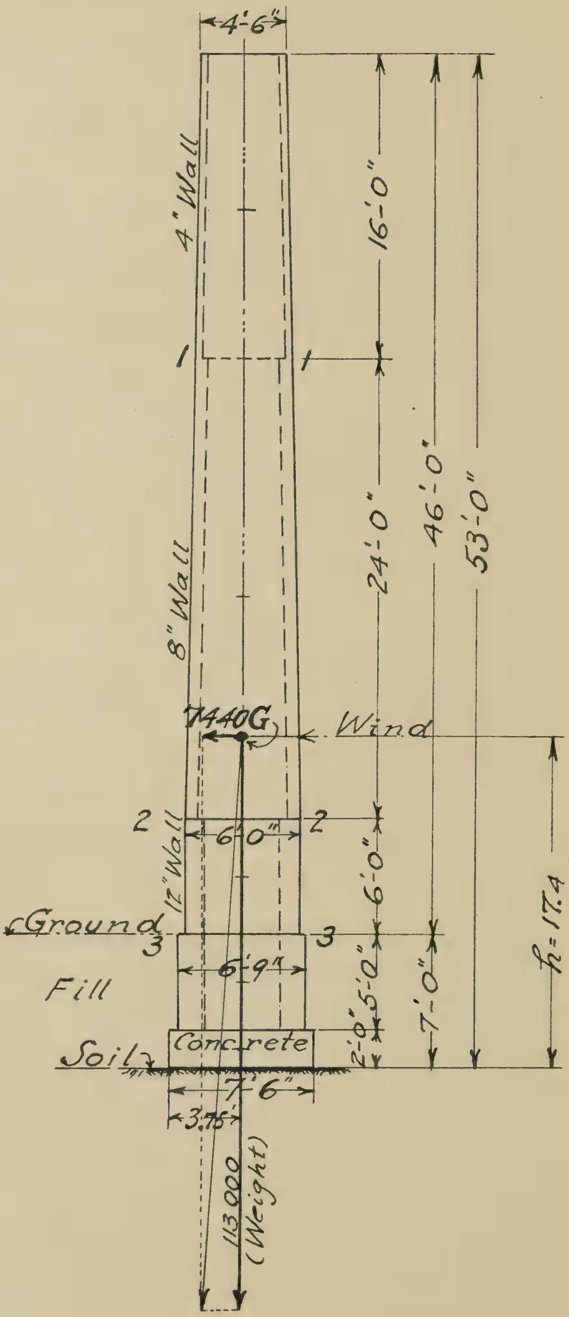

4'-6"
4" Wall
16'-0"
1
1
24'-0"
46'-0"
53'-0"
8" Wall
7440
G
Wind
2
2
6'-0"
12" Wall
6'-0"
Ground
3
3
6'-9"
Fill
5'-0"
7'-0"
h = 17.4
Concrete
2'-0"
Soil
7'-6"
3.75'
113000 (Weight)

FIG. 2.

2. Safety at Base against Overturning Due to Wind Pressure (Fig. 2).—We will consider the stack as an upright column, neglecting the lining and the earth below ground since the lining should be independent and would add but very little to the stability of the stack and the earth may be removed during the construction of the stack.

The effective wind area above ground is 248 square feet. Taking a wind pressure of 30 pounds per square foot, we have a total wind pressure of 7440 pounds. This should be concentrated at the center of gravity of the total stack in reference to the bottom, hence in our case at a distance of 17.4 feet from the bottom. The wind moment or overturning moment then is 7440 times 17.4 equal to 129,456 foot pounds, and the resisting moment 113,000 times 3.75 (weight of stack without lining times distance from center to outer edge of foundation) equal to 423,750 foot pounds, exceeding the overturning moment nearly 3.3 times.

A wind pressure of 7440 pounds and a stack weight of 113,000 pounds (stack without lining) are graphically shown in Fig. 2 with a resultant but very slightly in excess of 113,000 (stack weight), hence we see that in our case the influence of the wind upon the base is negligible.

3. Safety of Stack Column against Breaking.—In order to investigate the strength and safety of the stack column, it is best to take the bottom of each section. The different sections, marked 1–1, 2–2, 3–3, in Fig. 2, have been redrawn in Fig. 3, showing the forces acting upon each section.

Section 1–1.—The effective wind area is 75 square feet and the wind pressure 2250 pounds acting in the center of gravity of this section. Hence the overturning moment is 2250 times 7.8 equal to 17,550 foot pounds.

The resisting moment is the weight times its lever arm or 12,800 pounds times 2.5 feet equal to 32,000 foot pounds.

We see that the resisting moment is 1.8 times larger than the overturning moment.

Section 2–2.—The effective wind area above this section is 210 square feet and the wind pressure 210 times 30 or 6300 pounds acting in the center of gravity of the total. Hence the overturning moment is 6300 times 16 equal to 100,800 foot pounds. The resisting moment is 58,000 times 3, equal to 174,000 foot pounds, being 1.7 times larger than the overturning moment.

Section 3–3.—The effective wind area is 246 square feet and the wind pressure 7380 pounds, resulting in an overturning moment of 7380 times 17.9 or 132,100 foot pounds.

The resisting moment is 75,000 times 3 or 225,000 foot pounds, being 1.7 times larger than the overturning moment.

We have seen that a kiln stack, so far, seems to be a very safe proposition in regard to stability. A kiln stack is very different from a power stack. In the first place it is usually a good deal lower than a power stack, and in

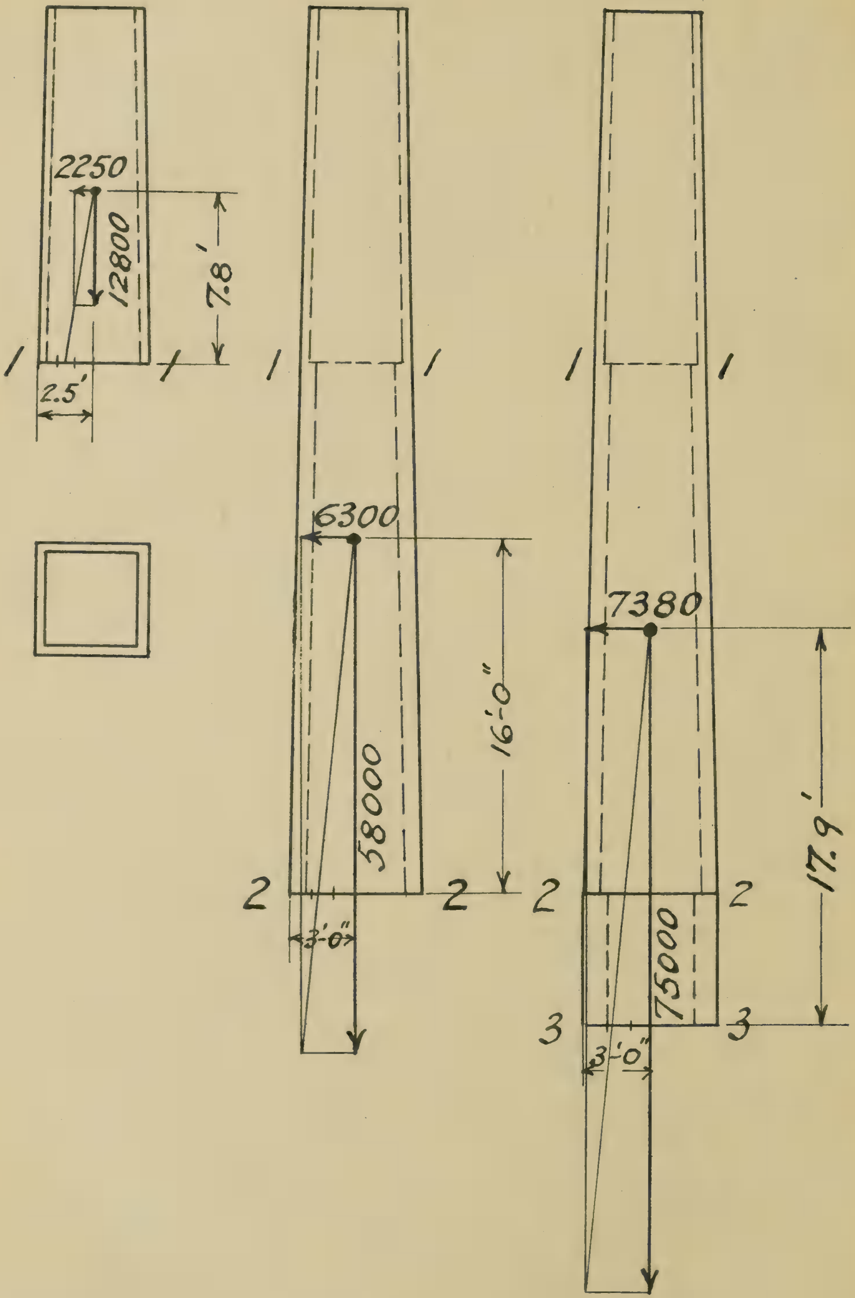

12800
7.8'
2.5'
16'-0"
58000
3'-0"
17.9'
75000
3'-0"

FIG. 3.

the second place the base or foundation has to be comparatively large to accommodate the underground draft flues and the additional brickwork around the flue intakes.

However, the above calculations do not take into consideration the thickness of the walls for the various sections, hence it will be necessary to figure the stack sections for compression and tension like ordinary beams, fastened at one end.

If we call

P, weight of stack or stack section
A, area of cross-section
M, bending moment
S, section modulus of cross-section

we get for the fiber stress per square foot the expression

$$f = \frac{P}{A} \pm \frac{M}{S}$$

where plus stands for half of stack column opposite the wind, and minus for half of stack column facing the wind.

All the calculations are in pounds and feet.

Hence we have:

Section 1–1 (see Fig. 4)

$$P = 12{,}800$$
$$A = 6.3$$
$$\mathrm{M} = 2250 \times 7.8 = 17{,}550$$
$$S = \frac{5.1^4 - 4.44^4}{6 \times 5.1} = 9.4$$

(Section Modulus from any engineering handbook.)

or

$$f = \frac{12{,}800}{6.3} \pm \frac{17{,}550}{9.4}$$
$$= 2032 \pm 1867$$

$= 3899$ pounds per square foot for side opposite wind
$= 165$ pounds per square foot for side facing the wind.

Section 2–2 (see Fig. 4)

$$P = 58{,}000$$
$$A = 10.9$$
$$M = 6300 \times 16 = 100{,}800$$
$$S = \frac{6^4 - 4.7^4}{6 \times 6} = 22.4$$

or

$$f = \frac{58{,}000}{10.9} \pm \frac{100{,}800}{22.4}$$
$$= 5322 \pm 4500$$

$= 9822$ pounds per square foot for side opposite wind
$= 822$ pounds per square foot for side facing wind.

Section 3–3 (see Fig. 4).

$$P = 75{,}000$$
$$A = 20$$
$$M = 7380 \times 17.9 = 132{,}102$$
$$S = 29$$

or

$$f = \frac{75{,}000}{20} \pm \frac{132{,}102}{29}$$
$$= 3750 \pm 4555$$

= 8305 pounds per square foot for side opposite wind

= −805 pounds per square foot for side facing wind, being tension.

These calculations bring out the fact that practically all sections are very safe with the exception of the last section 3–3 where it faces the wind. Since the wind may blow from any direction, it is advisable to strengthen this section all around at the bottom by running the 16-inch wall a few courses higher and stepping down to a 12-inch wall, as shown in Fig. 5.

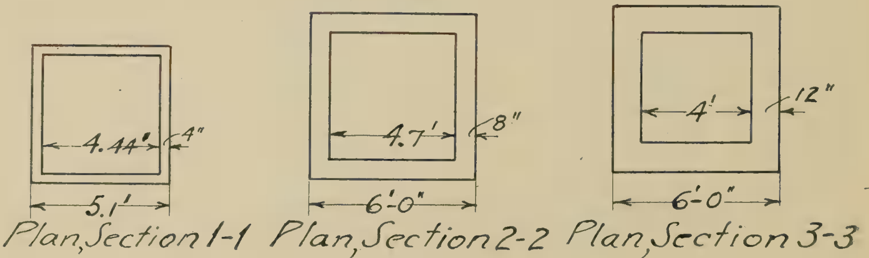


FIG. 4.

Refiguring this section now with the above correction, we get for: Section 3–3 (see Fig. 5).

$$S = \frac{6.75^4 - 4^4}{6 \times 6} = 57$$
$$f = 3750 \pm \frac{132{,}102}{57}$$
$$= 3750 \pm 2317$$

= 6067 pounds per square foot for side opposite wind

= 1433 pounds per square foot for side facing wind.

While small tension values perhaps cannot always be avoided in stack design, yet a correction and hence safeguarding can easily be introduced as illustrated above.

It is necessary to make calculations referring to the thickness of the wall of each section, and it is evident that no other calculation can be considered conclusive as regards stability of stack.

Practical Requirements

For pointing out the practical requirements we refer to Figs. 6 and 7. In Fig. 6 we have a double and in Fig. 7 a single stack, both being dampered with cold air instead of a sliding gate which is of short life, mostly leaks and seldom works. The stack Fig. 7 is shown tapered while the one in Fig. 6 has perpendicular walls which sometimes can be built quicker with inexperienced bricklayers in tapered work.

A concrete slab at the bottom of the stack is a good feature to distribute the weight uniformly over the soil and to insure uniform settle. However, care must be taken to properly protect the concrete against the heat from the flue to prevent its cracking and disintegration.

It is absolutely necessary to leave an expansion joint, as shown, between the end of the main draft flue from the kiln and the stack.

The main draft flue will naturally be low on account of the kiln bottom, and it is advisable to step up at the outside of the kiln, as shown, and place the entrance to the stack just below ground. Outside of the small saving in excavation, it will enable better access of the outside air for dampering or checking the draft, and also for cooling the kiln after the burn.

It is necessary to strengthen the lower part of the stack sideways of the flue inlets, as shown on plan.

Instead of placing the cold air inlet over the flue as shown, it can also be placed in the bottom of the stack

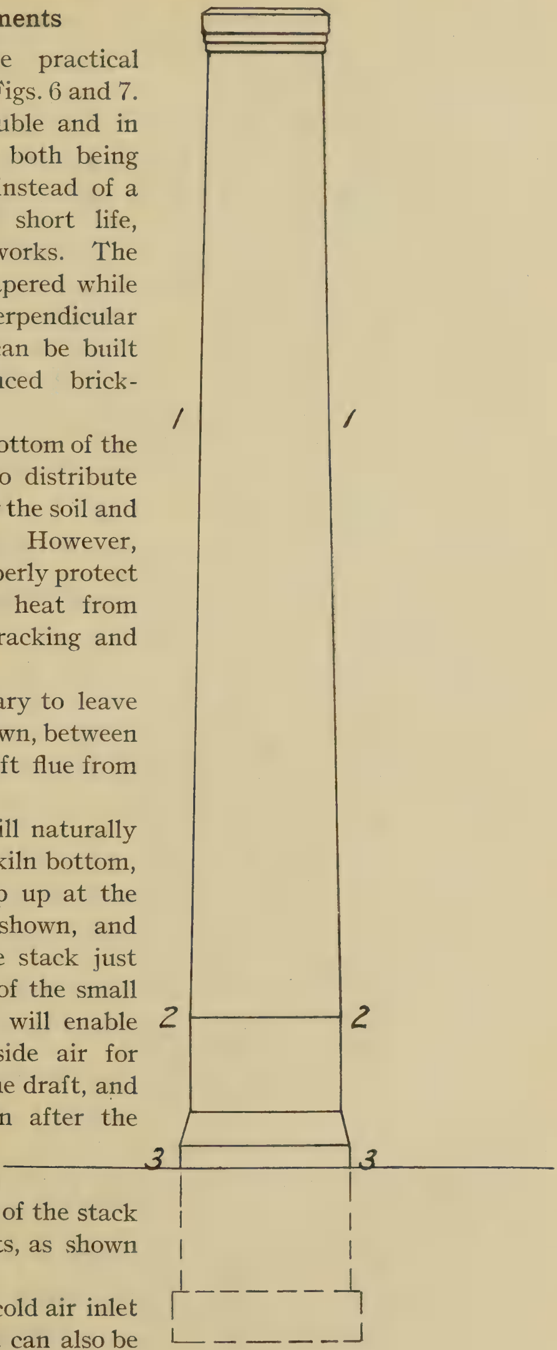


FIG. 5.

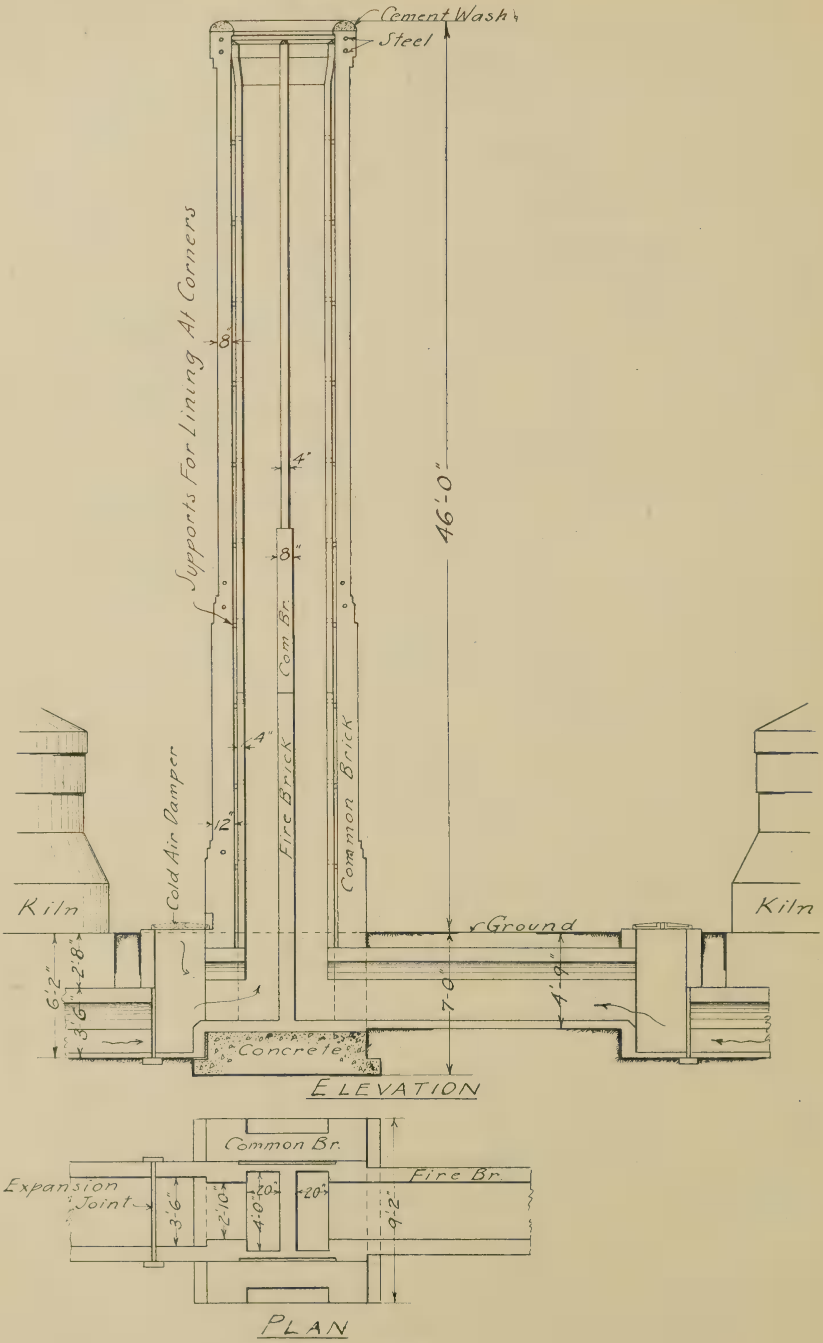

Cement Wash
Steel
Supports For Lining At Corners
8"
4"
46'-0"
8"
Com Br.
Fire Brick
Common Brick
4"
12"
Cold Air Damper
Kiln
Kiln
Ground
6'-2"
2'-8"
3'-6"
7'-0"
4'-9"
Concrete
ELEVATION
Common Br.
Fire Br.
Expansion Joint
3'-6"
2'-10"
4'-0"
20"
20"
9'-2"
PLAN

FIG. 6.

above ground, on any side of the stack except the one facing the kiln. Then we can place the stack closer to the kiln to give more room for coaling. Such an opening could also be used for an auxiliary furnace for getting draft in starting up or watersmoking. However the damper for such an opening could not be as simple and positive as the plate above the flue opening shown, and the stack would naturally be weakened here unless the opening is kept narrow or the cross-section is strengthened accordingly.

We see the fire-brick lining resting on solid foundation, independent of the outer wall and carried to the top of the stack. The lining is supported by bricks projecting out from the outer wall, two at the corner above each other, as shown in Fig. 8. In order to make sure that the expansion of the lining will not affect the outer brickwork, these projections can be staggered, in other words they go around the stack in form of a spiral and are never opposite one another. The main expansion of the lining, however, is upward and if the coping projects into the stack, there should be left enough space between the bottom of the coping and the top of the lining to allow expansion of the lining upward.

There is no reason why openings should be left in the outer brickwork which will cool the stack and diminish its pull. Only concrete stacks require such openings.

There should be no abrupt change from a heavy to a lighter wall but it should be done gradually by stepping off the brickwork.

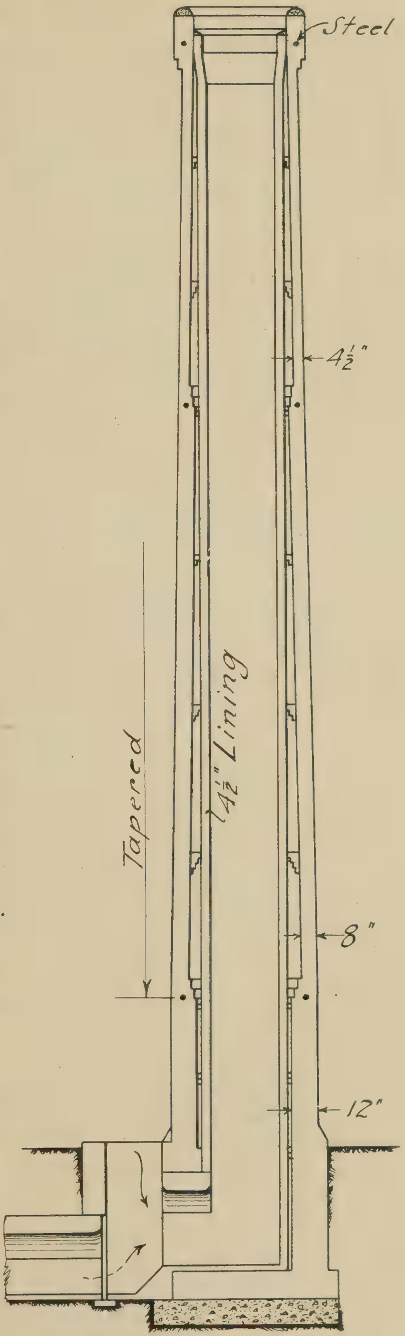


FIG. 7.

There can be found all sorts of copings, but the one illustrated in Fig. 9 we claim to be the most practical one. There is a dry joint in the lining to allow the air to escape from the air space in heating and expansion or a small hole can be left in the lining somewhere on top. A heavy concrete top and cement wash over the top will tie the brickwork and shed all water. The lining also should have a cement wash. The cement coping should be put on as dry as possible and covered with wet rags after completion so that the surface does not dry too rapidly causing cracks. It is most important to avoid cracks in the coping because water and frost will commence their gradual destruction here, easily and unseen.

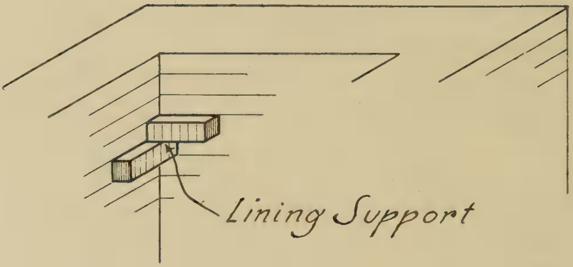


Fig. 8.

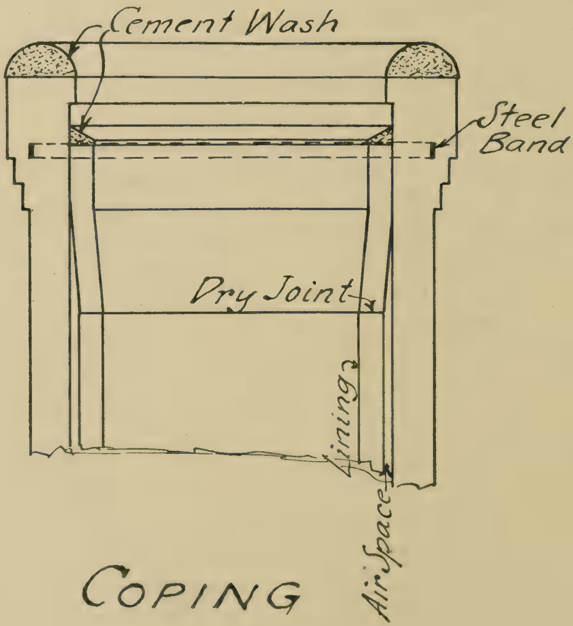


Fig. 9.

It is very good practice to embed an iron band or iron rod, in form of a closed frame, on top within the brickwork, as shown, to tie the brickwork and keep it from spreading. This can also advantageously be done in each section where a reduction in wall thickness takes place. It is a mistake, however, to use any kind of steel outside of the stack since it will rust and finally fail. The outside tieing of a stack should only be resorted to as a means for repairing and safeguarding a badly cracked stack. A properly constructed stack will not crack.

In nine cases out of ten, if the clayworker has to add more kilns and stacks to his equipment, he will build the stacks just as they have been built before, for only the reason that they stood up and hence evidently are all right. The question whether the stacks have a close margin of safety or are built with a waste of material does not enter into his mind.

Highly theoretical calculations do not have to be made, and we have pointed out a way of checking the safety of a stack with a small amount of mathematical work. The practical pointers given, we believe, are worthy of consideration. The neglect of so-called details may swing the balance from success to failure.

PAXTONVILLE, PA.

JOURNAL AMERICAN CERAMIC SOCIETY

Preparation of Abstracts

Every article in THIS JOURNAL is to be preceded by an abstract prepared by the author and submitted by him with the manuscript. The abstract is intended to serve as an aid to the reader by furnishing an index and brief summary or preliminary survey of the contents of the article; it should be suitable for reprinting in an abstract journal so as to make a reabstracting of the article unnecessary. The abstract should, therefore, **summarize all new information completely and precisely.** Furthermore, in order to enable a reader to tell at a glance what the article is about and to enable an efficient index of its subject matter to be readily prepared, the abstract should contain **a set of subtitles** which together form a **complete and precise** index of the information contained in the article. This requires at least one and often several subtitles even for a short abstract.

In the preparation of abstracts, authors should be guided by the following rules, which are illustrated by the abstracts in THIS JOURNAL for February and March, 1921.* The **new information** contained in an article should first be determined by a careful analysis; then the subtitles should be formulated; and finally the text should be written and checked.

Rules

1. **Material not new** need not be analyzed or described in detail; a valuable summary of a previous work, however, should be noted with a statement indicating its nature and scope.

2. **The subtitles should together include all the new information;** that is every measurement, observation, method, improvement, suggestion and theory which is presented by the author as new and of value in itself.

3. **Each subtitle should describe the corresponding information so precisely** that the chance of any investigator being misled into thinking the article contains the particular information he desires when it does not, or vice-versa, may be small Such a title as "A note on blue glass," for example, is evidently too indefinite a description of information regarding "Absorption spectra of glass containing various amounts of copper-cobalt and chromium-cobalt." General subtitles, such as "Purpose" and "Results" should not be employed as they do not help to describe the specific information given in the article.

4. **The text should summarize the authors' conclusions and should transcribe numerical results of general interest,** including those that might be looked for in a table of physical and chemical constants, with an indication of the accuracy of each. It should give all the information that anyone, not a specialist in the particular field involved, might care to have in his note book.

5. **The text should be divided into as many paragraphs** as there are distinct subjects concerning which information is given, but no more than necessary. All parts of subtitles may be scattered through the text but the subject of each paragraph, however short, must be indicated at the beginning.

6. **Complete sentences** should be used except in the case of subtitles. The abstract should be made as readable as the necessary brevity will permit.

7. The ms. of all abstracts must be typewritten and double or triple spaced.

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* The rules were prepared by the Research Information Service of the National Research Council. The Society is indebted to Dr. G. S. Fulcher of the Corning Glass Works (formerly with the National Research Council) for the rules and the illustrative abstracts.

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ORIGINAL PAPERS

MECHANISM OF PLASTICITY FROM COLLOID STANDPOINT[1]

BY G. A. BOLE[2]

ABSTRACT

Introduction.—Brief statement of present conceptions of the colloid chemists.

Theory.—Plasticity is caused by the enveloping film of colloidal material which surrounds the clay grains, this film being of opposite polarity to the grain proper. Addition of electrolyte acting as deflocculant causes outer layer of film to be attracted to ion of same polarity as clay particle, thus reducing effective diameter and increasing polarity of plasticity inducing particles. Particles which were held by surface forces of "particles in contact" are no longer in contact and are actually repelling each other due to like and increased polarity. A flocculating ion drives action in opposite direction causing an increase in depth of colloid film thereby increasing surface in actual contact and decreasing repulsive force of plasticity inducing particles. Transport numbers as well as polarity are governing factors in ions of electrolytes.

Measurements.—Touch method is proven to be unreliable. Desirability of a unit of measurement. Plea for a unit of colloidality and standard method for measurement.

Introduction

Matter in the colloidal state means simply that any species of matter, if sufficiently subdivided, becomes colloidal. Whether it be a gel or suspension depends on its state of subdivision or dispersion. Any kind of matter may, theoretically at least, appear in the form of a jelly. We will use the term "gel" to indicate an agglomerated sol. The term "gel" is meant to include a jelly but is in no way synonymous with it. Ceramists prefer the terms "flocculated" and "deflocculated" to indicate that a clay is in the "gel" or "sol" state, respectively. We shall use the term "colloid" to

[1] Published with the permission of the Director of the U. S. Bureau of Mines.

[2] This presentation is the written form of a talk given before the annual meeting of the American Ceramic Society.

indicate those particles with a diameter of 0.0005 mm. to 0.000005 mm.; these limits are of course somewhat elastic. The prime requisite to colloidality, with a few exceptions which do not concern us, is that the material in question be highly insoluble in the suspending medium, such as clay in water.

The colloids in clay are very largely at least crystalline in nature. The X-ray spectra we hope will tell us shortly just to what extent this is true.

Since the colloidal state of matter is a case of subdivision, we could call it the state of large surfaces; *i. e.*, as we subdivide an object, its surface becomes larger in comparison with its mass. So, for a given quantity of material in the colloidal state, we have relatively enormous surface areas. So any phenomena with relation to the surface will be greatly multiplied as we approach and proceed through the colloidal state of subdivision. Some of these phenomena are: surface tension (interface forces); cohesion (as a mass); adhesion; adsorption, etc.

We may then further define the colloidal state as the state of augmented surface phenomena.

The factor which interests us most just now is adsorption; it is a property that every surface has, and for a given substance varies directly as the surface area. Since adsorption is a selective phenomenon, all substances are not adsorbed to the same extent upon a given surface. The minerals which go to make up a clay adsorb electrolytes very strongly and to a lesser degree some colloids; always remembering that these minerals themselves comprise, for the most part at least, the colloid as well as the larger agglomerates.

Since a clay consists of a collection of particles with diameters ranging all the way from that of simple molecules (adsorbed salts) to that of particles plainly visible under the low power microscope, we may ask what proportion of this collection is of colloidal dimensions. Recent work would seem to point to their being roughly in the neighborhood of 10 to 40 per cent in the clays examined.

No matter what our views may be as to the mechanics of plasticity and its measurement, I believe we can agree that it is summed up in the internal forces which resist the free passage of clay particles (macroscopic, microscopic, or submicroscopic) over each other.

If the force of gravity is sufficient to overcome this friction, we call the motion induced, viscous flow; if a force greater than gravity is required to overcome the frictional resistance, we call it plastic flow, and the force required, the yield value. Since this friction between the particles takes place only at the surface of the particle, it is very evident that it will be greater the greater the contact surface area. In other words, the nearer the individual particles approach colloidal dimensions, the greater the yield value, or the greater the plasticity factor.

The fact that an electrolyte may first cause a slip to decrease in viscosity, then increase, and again slowly to decrease as progressive concentrations of electrolyte are used, is explained by one authority as being due, first, to deflocculation of the particles, second, to the "salting out" effect as illustrated by soaps and the third stage as a dehydration or squeezing out of water from the already flocculated agglomerates.

Theory

I like to think of the mechanics of the clay water system as follows: Let us mentally picture the vertical cross section of a hypothetical clay suspension—particles with their adsorbed films. The particles themselves may be either microscopic or sub-microscopic and the adsorbed film of submicroscopic material either amorphous or crystalline—it makes no difference. The system is, let us say, a clay cream just too thick to flow without addition of an electrolyte.

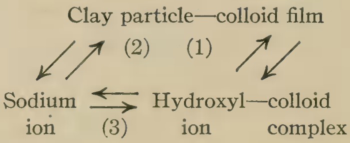
The clay particles have the power of adsorbing strongly on their surfaces these other particles, due to their surface energy (probably of a negative electrical character), the surface film being of positive polarity as regards the adsorbing particle. This film is in effect a dielectric and the clay particles, together with their adsorbed films, are in effect neutral bodies which are subject to the laws of attraction and repulsion. This constitutes a part of the frictional force that is required to be overcome, and is included in the yield value. If the particle is small enough to possess a Brownian movement of sufficient amplitude it will stay in suspension, and if not it will slowly settle in accordance with Stokes' law. We have then, in the case of the larger particles including their adsorbed films, in effect two electrically neutral bodies in contact. The force with which the outer layers of this film is held varies inversely as its thickness. So, as we apply a force of given magnitude, it will at first cause it to slip. The very slight elasticity shown by a clay in passing from a die may be caused by the surface film.

We conceive plasticity, as understood by the ceramic man, to be due to this surface film of colloidal material—amorphous or crystalline, organic or inorganic—and these films to be not of relatively great thickness.

If then we wish to control the force (yield value) required to induce flow, we must control the depth of the surface film. This can be done with electrolytes (charged bodies). If we add NaOH to such a system, we will upset the adsorption equilibrium. The ions of NaOH in equilibrium with the system will function as follows:

The negatively charged OH^- ions will attract the outer layers of the film material with greater force than the less negative clay particles, forming a colloid-hydroxide complex, which can be assumed to be either a chemical individual or a colloid with OH^- nucleus. We prefer to consider it a very slightly ionized chemical entity. This process goes on until an adsorption equilibrium is set up.

During this process we have done two things—both of which will cause a fall in viscosity. We have removed the outer films from the clay particles, thus reducing their effective diameters, and so reducing friction. We have also displaced the practically electrically neutral bodies by bodies with like charges (negative), thus introducing repulsive forces, which will permit mobility. Schematically the equilibrium may be represented as follows:.



The positive Na ion is in electrostatic equilibrium with the two negatively charged bodies.

There is no tendency for Na^+ to be adsorbed on a positive film but a great tendency for a positive film to unite with a negative OH^- ion to form a colloid-hydroxide complex.

As the concentration of the ions of NaOH is progressively increased the tendency for action (1) to take place decreases due to progressive removal of positive colloid film, but for action (2) to increase due to increased negative polarity of the clay particle. Action (3) is of minor importance.

Viscosity falls while action (1) is in ascendance due to removal of film, plus repulsion of aforesaid friction inducing bodies, while it increases as action (2) increases due to decreasing polarity of friction inducing bodies. When polarity has approached zero, we reach a high point in viscosity due to internal friction but not in plasticity, as plasticity is induced largely by the *larger* clay particles with their adsorbed films, while now we have clay particles with thin films and loosely combined colloid—OH ion complexes.

If this is true, we would expect a curve with great pitch at first on addition of electrolyte that would taper off and then start up. This is what we actually do get.

If NaOH is added beyond a concentration sufficient to give a neutral body, it is possibly combined molecularly to form: (a) NaOH—film colloid complex, and (b) $NaOH\text{-}OH^-$—colloid complex, both of which are ionized, giving Na^+ and negative complexes which will again repel each other and lower viscosity.

When H^+ ion is added to such a system, the effect is to combine with the OH^- of the hydroxyl-film complex, thus forming H_2O and liberating some of the positive colloid which is then free to be adsorbed as outer layers on the clay particles system.

It is in effect a driving of the equilibrium in the opposite direction thus effecting an increase of the plasticity producing film.

The flocculating or deflocculating effect of the ions of an electrolyte depends not only upon their polarity and concentration but also upon their transport numbers, the speedier ions such as H^+ and OH^- having the greater effect. The concentration of the hydrogen ion (pH) as measured against a hydrogen electrode should throw light upon flocculation and deflocculation. If such a theory as the above is correct one would predict a break in the curve at pH-7 and an increase in dispersion as the pH value increased and a flocculation when it decreased.

If the aging of clays is due to an increase of H ions, it may be explained as above suggested. Note that both the bodies capable of producing friction carry a negative charge, which agrees with cataphoretic considerations. The above outlined theory seems to clear up many of the physical changes which clay suspensions undergo. Any theory, such as the above, which seeks to explain physical phenomena is justifiable only if it explains known facts or if it points the direction in which research can hope to be productive. An enormous amount of exact experimental evidence is, of course, necessary to establish such a theory which in the case of clays is lamentably lacking. This phase of the work will be brought out in a subsequent paper.

Having thus taken considerable time to set forth my views (which are only a collection and expansion of already expressed theories) on plasticity, we will now consider for a while plasticity measurement.

Measurement

Many types of apparatus have been devised to measure this elusive property of clays and allied substances, but none of them has proved wholly successful, and as a result a great deal of preference is still expressed for the so-called touch or feel method.

In order to test out the reliability of this method so largely used in many quarters, we got the consent of five men, eminently fitted to judge clays, to undergo a series of tests, the results of which are shown in the accompanying table. Each observer tested five clays varying widely in degree of plasticity, ranging from ball clay to short kaolin. The first two observations were made blindfolded and the last observation was unrestricted. The observations were made several weeks apart and the observers were not aware that they were the same clays. The clays were made up to maximum plasticity just before each trial.

The four most satisfactory methods for measuring plasticity are probably the so-called Bingham plastometer method, the Stringer-Emery method, the Atterberg tests, and the dye absorption method.

The last named has lately fallen somewhat into disrepute due to the fact that it is a measure of a particular colloid rather than the total colloid content of clay and assumes that plasticity varies directly as colloid content.

It is possible to get duplicate results far more consistently than by any other method, unless it be possibly the Bingham method, which has not as yet been fully tried out on clay–water systems. The explanation of course is either that the colloids found in clays are largely the same or that the adsorptive power of the different colloids does not vary widely, and that plasticity is very closely associated with colloid content.

In explanation of the accompanying table, Observer (1) in his first (*a*) trial judged Tenn. Ball to be third (3) in order of plasticity of the clays tested, placed it (3) on second trial (*b*) also. These first two (*a*) and (*b*) trials were under blindfold (touch). His third judgment unblindfolded

TABLE I

TABLE: SHOWING ORDER OF PLASTICITY OF CLAYS AS JUDGED BY OBSERVERS USING TOUCH METHOD AND BASIS FOR JUDGMENT

Clay	Tenn. ball			Weathered shale			Bentonite			No. 2 fire			N. C. kaolin			
Method of observation	Touch		Unrestricted	Touch		Unrestricted	Touch		Unrestricted	Touch		Unrestricted	Touch		Unrestricted	Basis of judgment
	(a)	(b)		(a)	(b)		(a)	(b)		(a)	(b)		(a)	(b)		
Observer (1)	3	3	1	2	2	2	1	1	3	4	4	5	5	5	4	Smoothness Drying speed
(2)	1	2	1	2	1	2	4	4	3	3	3	4	5	5	5	Cohesiveness
(3)	2	2	2	1	1	1	3	3	3	5	5	5	4	4	4	Yield
(4)	1	1	3	2	2	2	3	3	1	5	4	4	4	5	5	Yield Cohesiveness
(5)	3	5	5	2	4	4	1	1	1	5	2	3	4	3	2	Adhesiveness Cohesiveness
Adsorption (dye)		3			2			1			4			5		
Atterberg test		3			2			1			4			5		

(unrestricted) was that Tenn. Ball was the first (1) in order of plasticity. In the last vertical column is indicated the property upon which he claimed to base his judgment.

In the two lower horizontal columns are indicated the order of plasticity as determined by the adsorption and Atterberg tests.

It would seem, then, that the touch method is not reliable when carried out by different men, even under the same conditions. More than this, however, it is of course highly desirable to be able to state in concrete terms—a unit or series of units, if necessary—the *degree* of plasticity of a clay, so that a man on the Pacific Coast may understand a man in St. Louis, when he says one clay is twice as plastic as another, and not have to depend on the comparatives, very, most, little, least, etc.

Our literature, as well as our technology, suffers enormously from the lack of a standard of comparison. The first thing which needs to be clarified is a definition of terms. This we must have even before we can discuss intelligibly the factors involved.

It seems futile to try to measure a quantity upon which we are not agreed even to the extent of the factors involved. If, however, we can group all these unknown factors under one term, such, for instance, as "p," we can later dissect "p" in some such formula as the following:

$$p = \frac{\textit{deformation}}{\textit{force}} \quad \textit{or} \quad p = \frac{\textit{flow}}{\textit{yield value}}$$

We know that in "p" are involved several factors, such as cohesion, adhesion, surface tension, etc., and it is very desirable that they should be determined, but we do not need to mark time until this is done.

Specific references have not been given in this article, but the published works of Bancroft, Zsigmondy, Roland, Odén, Washburn, Purdy, Ashley, Bingham, Atterberg, Stringer, Emery, Von Veimaren, Alexander, Schurecht, Mellor, and others have been freely consulted and used.

CERAMIC EXPERIMENT STATION
U. S. BUREAU OF MINES
COLUMBUS, OHIO
April, 1922

Discussion

BY MR. PURDY:—The correctness in definition of colloidality, as given by Mr. Bole, cannot be questioned, but it should be understood that an all-inclusive general definition is bound to be much too broad for any particular colloid. All-inclusive definitions are misleading as are such theoretical statements as "any kind of matter, may, theoretically at least, appear in the form of a jelly"—for practically many colloids have not been found in and cannot be made to assume the jelly-like condition.

Subdivision of matter may be one of the conditions of colloidality but fineness of grain *per se* is not the whole story of colloidality and certainly it is not the cause of distinguishing properties of different types of colloids. Types of colloids are distinguished by properties other than size of particle. It can be said, however, that with materials in the form of discrete particles, as the size of particle diminishes, its specific surface is increased and with this there is an increase in intensity of surface effects. The smaller the clay particle, the more pronounced will be its behavior as a colloid.

Among the several classifications of colloids, two are of particular interest to ceramists, (1) emulsoids, and (2) suspensoids. Very few materials correspond in all particulars with those that are pronouncedly and distinctly of one type or the other, but those colloids which do correspond in all particulars to each of these types have very pronounced distinguishing properties and physical reactions.

Is a clay a suspensoid or an emulsoid? There are different sorts of suspensoids and emulsoids, and each sort has its own peculiar properties but there are determining characteristics for each class.

Viscosity.—The viscosity of a suspensoid, whether it be a solution or a turbid suspension, is not much greater than the liquid medium or solvent and is not increased greatly with increased concentrations. Whereas, the viscosity of emulsoids increases with increased concentrations.

Clay "slips" agree more nearly with emulsoids in this respect.

Flocculation.—Suspensoids are easily flocculated by electrolytes while emulsoids are not.

Clay slips behave in this more like suspensoids.

Change in State.—The emulsoids when dried and rewetted will revert to the same physical state as before. Suspensoids will not as a class so revert. In this respect clays behave more like emulsoids.

These and other contradictions are not surprising, for colloidality is not any particular state or condition and is not predicated by any set of conditions and, therefore, there is no particular definition of colloidality.

Have plastic clay particles a film of material in a colloidal condition? Put into another form this question can be: do the colloidal clay particles require a film of another material in colloidal condition in order to exhibit plasticity? If so, what is this plasticity-giving material?

Certainly the hydroxides of alumina and silica do not meet the requirements. They will not deflocculate with electrolytes. They will not revert to their original colloidal state after having been dried. Additions of any proportion of either of these hydroxides will not increase the plasticity of any clay yet experimented with; indeed after drying and rewetting, they decrease the plasticity.

Bole infers that this film about the clay particles is made up of yet smaller particles of the same material held by adsorption. The plastic, friction reducing material, according to this conception, consists of those clay particles that are so fine as to more nearly approach molecular subdivision.

This does not appear to me to be a necessary hypothesis. We have been unable to discover any colloidal material in clays essential to plasticity and have been unable, by addition of colloidal material, to increase plasticity. Certainly the finest portion of plastic clays obtainable by centrifuge separation neither subtracts from nor adds to plasticity.

It meets all the requirements in the way of a working hypothesis to assume that the plastic clay particles have sufficient specific surface (surface per unit volume) to allow the maximum development of the natural physical properties of the material, such as adsorption of salts, holding of a water film, and flocculating and deflocculating under the influence of a difference in tension between the salt water film and the salt solution in which the discrete clay particles are suspended. There is nothing in this assumption that is contrary or new to colloidal chemistry and it certainly plumbs more nearly with the several sorts of observations.

Much stress has been laid on the Brownian movement exhibited by some of the clay particles as evidence of electric charge. As a matter of fact, Brownian movement is evidence of a kinetic energy apart from electro static. Osmotic pressure (surface tension), Brownian movement and diffusion are markedly dependent upon the specific surface of the particles and not upon electric charges *per se*.

Clay particles are negatively charged and this is so whether flocculated or deflocculated. Flocculation by electrolytes does not render the particles neutral, as is evidenced by their traveling to the positive pole in electrosmosis tests. If the dielectric constant of the suspending medium is higher than that of the clay particle, as it generally is, the clay particle will show a negative charge. Flocculation and deflocculation has not been proved to be caused by changes in polarity of the clay particles. There is more evidence that flocculation and deflocculation result from tension differences.

A NEW TYPE OF GAS-FIRED VITREOUS ENAMELING FURNACE

By H. H. Clark

ABSTRACT

The furnace described in this article has a working chamber 4 feet wide by 3 feet high by 10 feet long, and is heated by ten gas burners, five on each side. Other proportions are made to suit the nature of the work to be enameled. City gas is most desirable, although any gas above the grade of producer gas may be used.

A furnace of this type can be brought to a working temperature in less than an hour, and will turn out from 12 to 24 loads of work an hour, depending on the kind of work being enameled.

The average gas consumption is about 1800 cubic feet of 500 B.t.u. gas per hour when firing about 600 square feet of flat ware totaling 690 pounds, representing 240 pieces, at an average temperature of 1700°F. The furnace runs without attention other than that given by the men who load and unload the fork.

Furnaces of the intermittent type have various features which are covered by patents issued and applied for. In addition to fuel economy, this type of furnace has the added advantage of producing ware of a very high gloss.

The first cost is low and no foundations other than the ordinary cement floor are necessary, as the entire furnace is above the floor level. Maintenance is practically nothing, as there is no muffle or combustion chamber.

If the following charts and photographs could be presented without further comment, leaving the rest to imagination, the author would be pleased, because to give all the details of a furnace such as this is very much of a problem.

On one hand the users of the furnaces hesitate about letting their competitors know about the improvements made in methods of burning on enamel that result in improved product and reduction of cost.

On the other hand the manufacturer objects to a detailed description of the furnace and of the method of operation for fear of losing a sale of his knowledge of such things. Ordinarily you cannot sell to a person that which you have already given to him. Then, too, a failure with a certain type of furnace because of faulty construction or incorrect operation makes difficult the promotion of such a furnace even under guarantee of correct construction and successful operation.

In this instance the writer is a third party who has represented both sides in the selection and operation of furnaces of this type, hence will endeavor to be fair with all parties concerned.

The general design of the furnace is shown in Fig. 1. Photograph of a furnace of this type, but without steel casing, is shown in Fig. 2. Figure 3 is an interior view of one of these furnaces after 20 months full operation, except for occasional shut-downs over Sunday. No repairs of any kind have been made, and indications are that none will be required for many more months.

Figure 4 is a photographic copy of pyrometer chart, showing how this type of furnace comes up to working heat after a 72-hour shut-down.

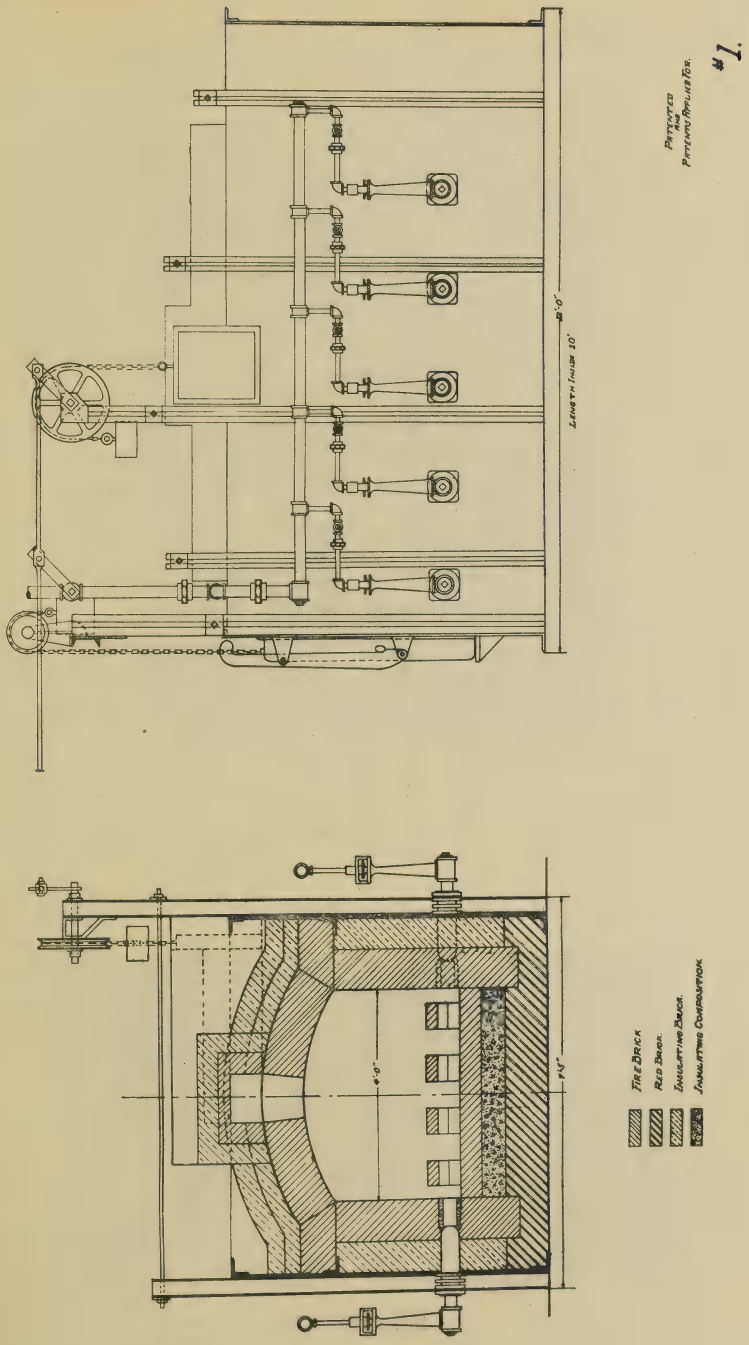

Patented
and
Patents Applied For.
#1.
12'-0"
Length Inside 10'
4'-0"
9'5"
Fire Brick
Red Brick.
Insulating Brick.
Insulating Composition

Fig. 1.

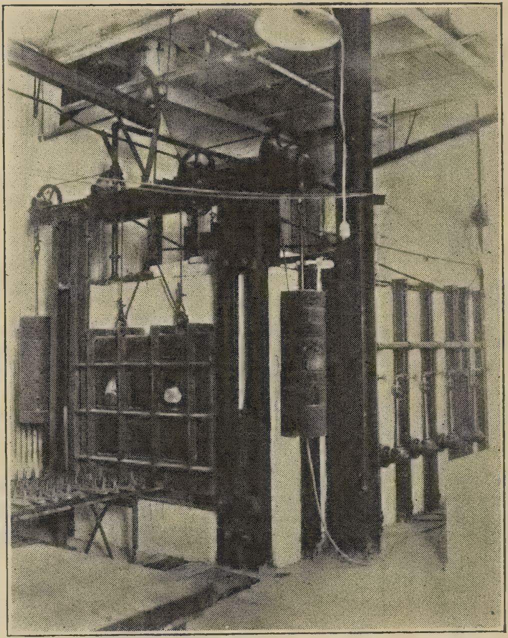


FIG. 2.

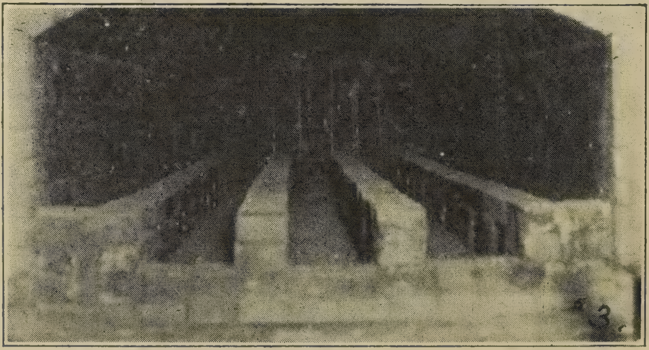


FIG. 3.

It also shows the variety of work done on that particular morning and an analysis of the chart runs about as follows:

4:10 Gas turned on. (Furnace at 750° after 72-hour shut-down)
4:53 Gas off. (Furnace at 1850° after 43 minutes firing)
4:55 First charge in
5:00 First charge out

From 5:00 o'clock until 7:35, a period of 2 hours and 35 minutes, a total of 36 loads was taken out of the furnace at a finishing temperature of 1600°F, consisting of 1003 square feet of first and second white coats on assortments of 22 and 24 gauge steel, consisting of splasher sides, panel tops, and broiler pans for gas ranges. Total net weight of material, 1140 pounds. Total number of pieces, 403. In addition to this, it required 220 pounds of supporting pins for each load, in order to give the proper support to this gauge of flat steel.

From 7:35 to 8:00 o'clock, 5 loads of ground coat, white, were taken out at a finishing temperature of 1700°F. Total square feet, 135. Net weight, 150 pounds. Total number of pieces, 50.

From 8:00 o'clock to 8:30, the furnace stood with the gas off while the workmen ate their meal.

At 8:30 the gas was turned on again and was ready for ground coat firing in 5 minutes, and from 8:35 to 9:20 a total of 10 charges of ground coat, white, were taken out at a finishing temperature of 1700°F. Total square feet, 270. Total net weight, 300 pounds. Total number of pieces, 100.

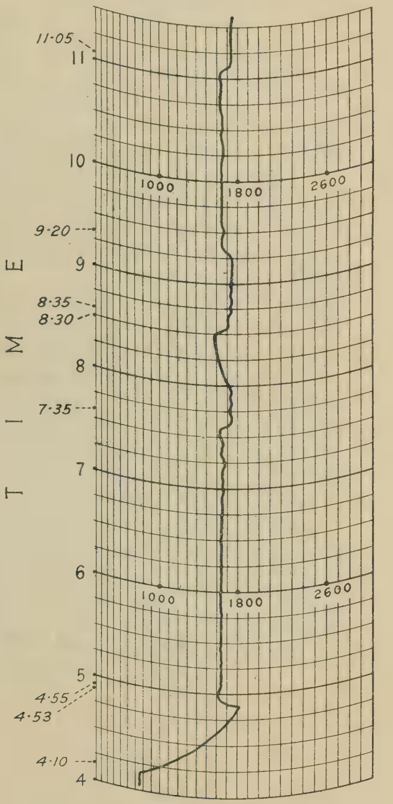


FIG. 4.

From 9:20 until 11:05 they resumed work on first and second white coat and put through 30 charges in this period at a finishing temperature of 1600°F, consisting of 1122 square feet. Net weight, 1295 pounds. Total of 438 pieces.

From 11:05 to 11:50 they were back on ground coat white, and in this period turned out 11 charges. Total square feet, 297. Net weight, 330 pounds. Total pieces, 110.

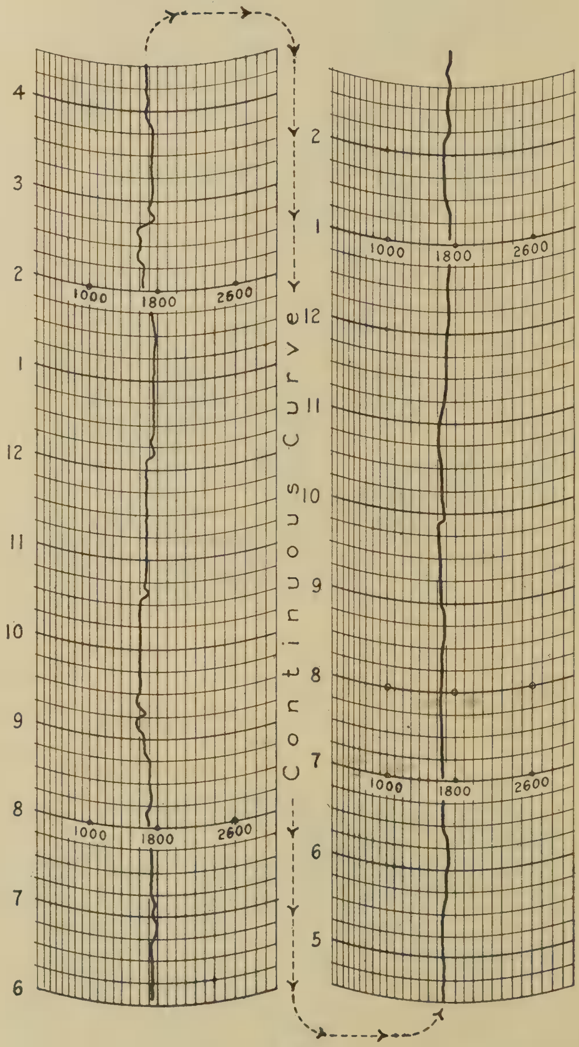

4
3
2
1
12
11
10
9
8
7
6
1000
1800
2600
1000
1800
2600
Continuous Curve
2
1
12
11
10
9
8
7
6
5
1000
1800
2600
1000
1800
2600

FIG. 5.

These figures, while taken from actual practice, are not the best obtainable, but are given to represent what can be expected under conditions as you find them the first few hours after starting the furnace after a shutdown of several days.

Figure 5 is a photographic copy of pyrometer chart for 21 hours' running, showing various temperatures for ground coat, first white coat, and second white coat on steel; also you will note 5 loads of cast iron were fired, 2 shortly after 9:00 and 3 more about 2:00 P. M. These were cast iron stove legs weighing approximately 3 pounds a piece, and 52 legs constituted a load.

Figure 6 is a photograph of a typical gas meter installation which is used for metering the gas to this type of furnace. The installation illustrated handles city gas of approximately 500 B.t.u.'s per cubic foot, and has a capacity of 24,000 cubic feet of gas per hour. The burning rate of each furnace is about 7200 cubic feet per hour, but for the short interval that the gas burns between loads, the gas consumed is less than 100 cubic feet per minute, and the total consumed is about 1800 cubic feet per hour. This installation will handle nicely, four of the furnaces described in this article, and this brings us to the item of cost.

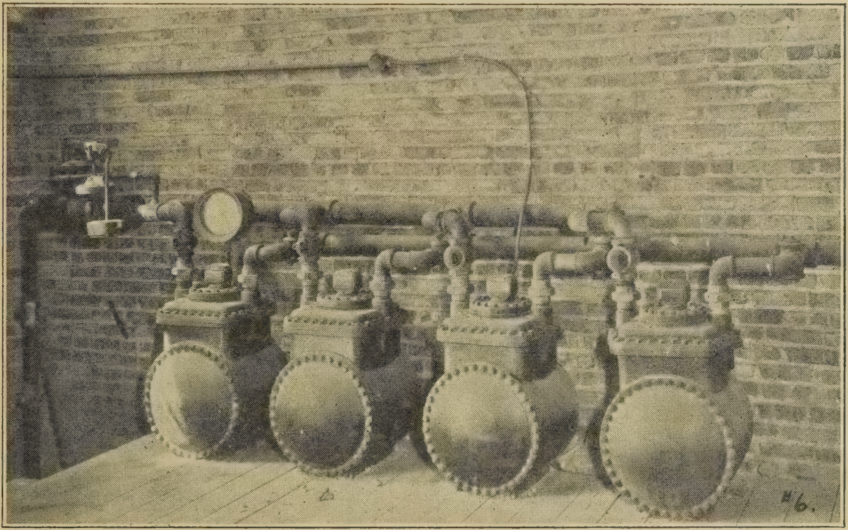
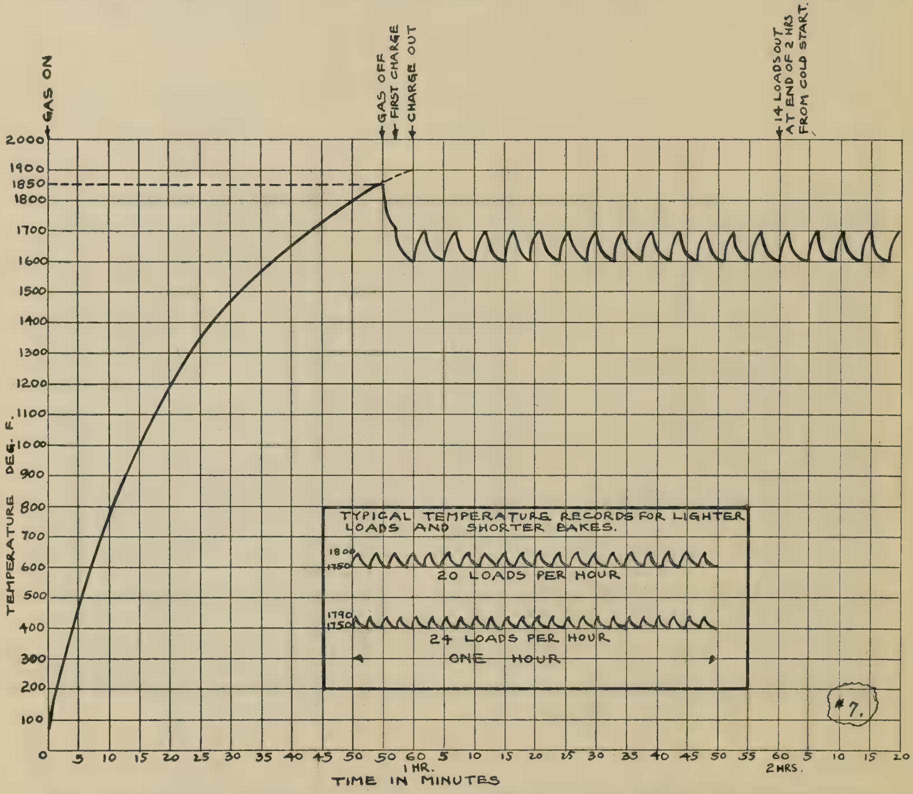


Fig. 6.

The average gas consumption for the 21-hour period shown on Chart 5 was 1800 cubic feet of 500 B.t.u. gas per hour, and at 50 cents per thousand this would represent a total fuel cost of 90 cents per hour per furnace. There was no other expense in connection with the fuel because the air for combustion is drawn in at the gas mixers by an automatic device known as an inspirator. The average production of material in this 21-hour period was 600 square feet per hour; average weight of material per hour, 690 pounds; average number of pieces per hour, 240; average finishing temperature, 1700°F. Two men did all of the work on this furnace, including loading and unloading fork, loading and unloading furnace, opening and closing the door, regulating the fuel, and so forth. The total labor expense per hour was therefore two men at 50 cents each. This makes a dollar an hour for labor and 90 cents an hour for fuel, a total of $1.90 per hour, which, divided by the production per hour on the class of goods previously mentioned, is, labor and fuel, 32 cents a hundred square feet or 27 cents per hundred pounds. These costs can be further reduced by leaving supporting pins in the oven, for certain classes of ware, also by use of flue gases in waste heat boilers and dry rooms. No exact figures



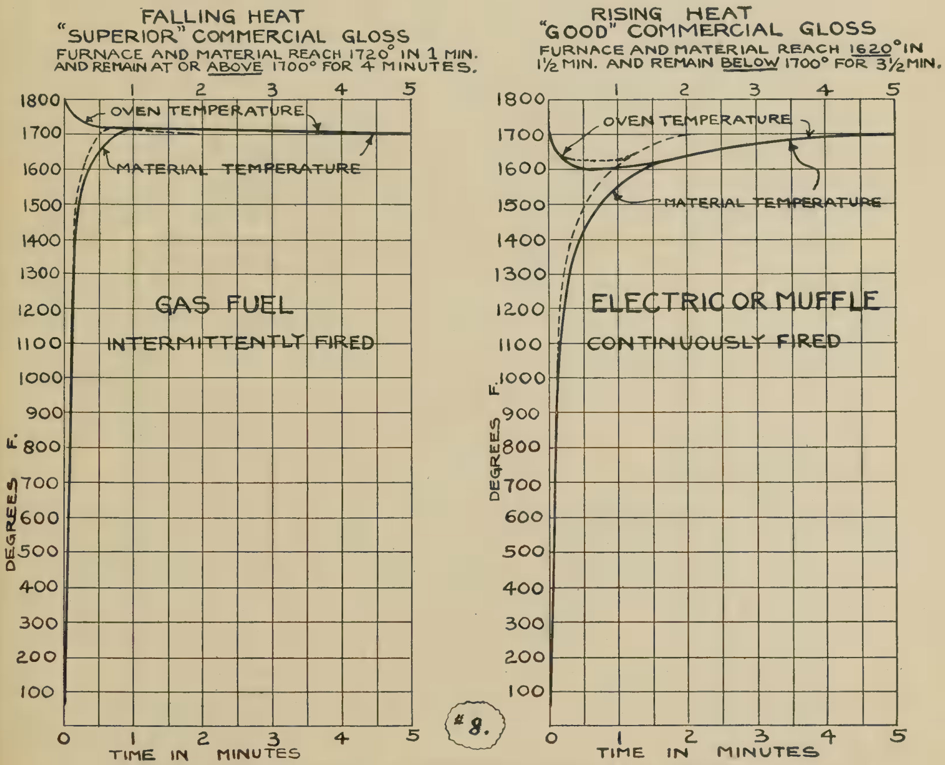
TYPICAL TEMPERATURE RECORD SHOWING START FROM COLD FURNACE TO WORKING TEMPERATURE AND PRODUCTION OF 14 LOADS OF MATERIAL, ALL WITHIN TWO HOURS.

NOTE:
ON 72 HOUR SHUT DOWNS, FURNACE DROPS TO 750° F. AND IS BROUGHT TO 1850° F. IN 45 MINUTES. BY INCREASING GAS SUPPLY AT BURNERS, EVEN GREATER SPEED IS POSSIBLE.

FIG. 7.

have been obtained as yet, but indications are that leaving pins in the oven reduces fuel cost about 18 cents per hour per furnace, and heat recovered from the gases by boiler and dry-rooms represent a further saving of about 18 cents per hour per furnace.

Chart 7 is a typical temperature record showing the start from cold furnace to working temperature and production of 14 loads of material all within 2 hours. Inserted in this chart are some typical temperature records for lighter loads and shorter heats. These charts are taken from actual pyrometer records, but on account of the frequent charges and short intervals of firing, the pyrometer record shows almost a straight line, due to the slight lag in the thermocouple.



FALLING HEAT
"SUPERIOR" COMMERCIAL GLOSS
FURNACE AND MATERIAL REACH 1720° IN 1 MIN. AND REMAIN AT OR ABOVE 1700° FOR 4 MINUTES.

RISING HEAT
"GOOD" COMMERCIAL GLOSS
FURNACE AND MATERIAL REACH 1620° IN 1½ MIN. AND REMAIN BELOW 1700° FOR 3½ MIN.

CHART SHOWING EFFECT OF TEMPERATURE ON GLOSS, AND ADVANTAGE OF FALLING HEAT IN THE INTERMITTENTLY FIRED GAS FURNACE WHEN USED FOR VITREOUS ENAMELING.

NOTE: ON LIGHTER WARE, WHICH CAN BE FIRED IN LESS THAN FIVE MINUTES, RESULTS ARE SIMILAR. DOTTED LINES SHOW TYPICAL TWO MINUTE BAKE.

FIG. 8.

Chart 8 shows a very important point in favor of the intermittently fired gas furnace, because the finished goods have a very high gloss. This has been attributed to the fact that the fusing of the enamel takes place at a falling heat. For example, when the door is opened to receive the goods, the furnace is at a temperature of 1800°F, although the desired finishing temperature is 1700°F. Careful observation with optical pyrometer and calculating the lag of our recording instruments indicate that it takes about a minute for the goods and the oven to come to the same temperature, and in doing this the furnace temperature drops about 80°F. Therefore, from that time on, whether the goods are in the oven 2 minutes or 3 minutes or more, they are under a slightly falling temperature which is approximately 3°F per minute.

Making similar observations on a muffle furnace, in which the finishing temperature of the goods was the same, namely 1700°F, we found that, not having the thermal head of 100° to start with, the temperature in the vicinity of the goods dropped to 1600°, and it took about a minute and a half for the oven temperature and the goods to equalize. After that period there was a slowly rising temperature, and if left in the oven approximately 5 minutes, the normal temperature of 1700° was restored; but if under these conditions the enamel was fused at 1600°F, it would evidently be still more liquid at the end of the bake, which would tend to thin the surface and diminish the gloss. On the other hand, if the enamel is compounded to be thoroughly melted at 1700°F, it only reaches this temperature for a fraction of the time, when compared with the intermittently fired furnace, which starts off with a thermal head of about 100° on heavy work and at least 40° on light work.

The big advantage of the gas fired furnace seems to be that, by distributing the fuel over a large number of small burners and designing them in such a way that combustion is self-starting and practically complete before the products enter the furnace chamber, rapid and economical combustion takes place, and the heat absorbed by the goods can be restored to the furnace in from 30 seconds to a minute and a half, depending on the class of work being enameled, or in any event within the time that it takes the 2 men to take the finished work off the fork and reload with work to be enameled. The opening in the main gas valve regulates the flow of fuel, and this determines the length of time to restore the furnace to proper heat.

In calculating the heat balance of the furnace on which these results were obtained, it is found that the average fuel consumption is about 900,000 B.t.u.'s per hour, of which about 15% goes into the enameled ware and about 20% into the loading pins. Here is where room for economy is possible, because on some classes of work the pins can be left in the oven. The other losses are radiation losses, flue losses, and heat lost each time door is opened.

In a furnace which is now under construction, the fuel consumption, it is thought, will be less than 700,000 B.t.u.'s per hour, because while no change is contemplated in the method of loading with pins, it is planned to use automatic temperature control which will shorten the period in which the furnace is under fire, and compressed air operated doors will shorten the time that the door is open. Furthermore, this latest furnace is being built with 9″ of insulating brick inside of the steel casing, so that radiation losses will be reduced to a minimum.

SOME PROPERTIES OF ZINC OXIDE BODIES[1]

By Earl E. Libman

ABSTRACT

Melting Point of ZnO.—The melting point of ZnO is above 1800°C and may be above its normal sublimation point.

Volume Shrinkage and Porosity of ZnO Bodies.—A very hard and dense body composed of pure ZnO can be prepared. At high temperatures it exhibits the unusual phenomenon of volume shrinkage accompanied by an increasing porosity.

Zinc Retort Bodies.—In the discussion the possible advantages of incorporating zinc oxide in a zinc retort body are mentioned.

1. Introduction.—The data presented below constitute part of an investigation which had for its purpose the determination of the Phase Rule diagram for the system $ZnO-Al_2O_3-SiO_2$. It was found, however, that, using pure materials, most of the temperatures of the diagram were beyond the range of any furnace equipment which the Department possessed and the investigation was therefore abandoned. The few data which were obtained, however, may be of some value to others interested in the behavior of zinc oxide and it seems, therefore, worth while to place them on record.

2. Material Employed.—The zinc oxide employed was a "chemically pure" material having the following analysis:

Fe.......	trace
Cu......	none
Cd......	none
Mn......	none
Pb......	0.01%

3. The Sintering of Zinc Oxide.—The material employed was in the usual form of a light fluffy powder which, on heating to a bright yellow heat, volatilized rather rapidly. Since the vapor pressure of a substance increases with increase in the convexity of the evaporating surfaces, it seemed probable that the high volatility of ordinary zinc oxide is caused by the combination of a great surface exposed and a high vapor pressure due to the smallness of the individual particles.

In order, therefore, to reduce the surface and to increase the size of the crystals, a sample of the zinc oxide was first placed in a desiccator and allowed to stand over damp filter paper until it had absorbed about 20 per cent of water. This moist material was found suitable for pressing, and cylinders 1.5 cm. in diameter by 5 cm. long were pressed out in a hardened-steel die, using a large hand operated screw press. These cylinders were then dried and the surface layer removed to eliminate any possible contamination with iron from the surface of the die. The cylinders

[1] Received March 8, 1922.

were then placed in a small platinum box with a tightly fitting cover and heated in a platinum resistance furnace to a temperature of 1400°C and held there for several hours.

Upon cooling, the cylinders were found to be extremely hard and stone-like. The outer surface was dark brown and numerous crystals, some as wide as 0.5 mm., had developed. The brown coating was found to be confined entirely to the surface, the inner portions of the cylinder showing a sparkling, coarsely crystalline aggregate. The dark superficial layer was ground off and upon analysis was found to contain 0.07 per cent Fe_2O_3, the source of which was probably the platinum box in which the sticks were fired. The interior portions of the cylinder after crushing and grinding in an agate mortar gave a yellow, heavy, crystalline powder, having the following analysis:

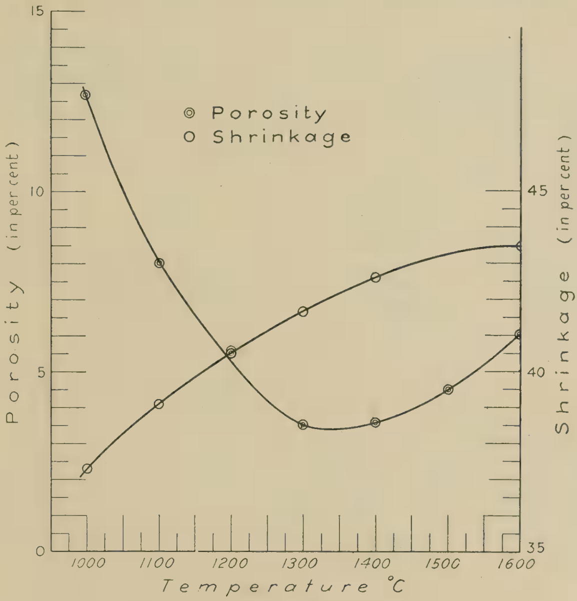


FIG. 1.

Fe..........	trace
Pb..........	0.01%
Cd..........	none
SiO_2........	0.03%, probably from the agate mortar
Al_2O_3........	trace, probably from the alundum furnace tube

It was estimated that if the yellow color of the powder was due to iron not more than 0.0005 per cent Fe_2O_3 was present. No attempt was made to determine the crystallographic properties of the crystallized material, but its general appearance under the microscope as well as its density (5.4) indicated that it was the mineral zincite.

4. Melting Point of Zincite.—A sample of material held for 48 hours at 1710°C showed no signs of fusion. A stick of the material was then heated in an oxyacetylene flame, using the apparatus and method described in a previous paper.[1] It was possible in this way to heat the end of a stick to a black-body temperature of 1800°C. It is not improbable therefore that the melting point of zincite is above 2000° and it may be that its sublimation temperature under atmospheric pressure is lower than its melting point.

5. The Burning Behavior of Zinc Oxide Bodies.—Cylinders of commercial zinc oxide were prepared by the dust-press process described above. After drying, their bulk volumes were obtained with a small mercury volumeter of the Seger type. They were then placed in an alundum-tube furnace wound with a platinum heating coil and were fired at the rate of 200°C per hour, trials being drawn at the following temperatures, 1000°, 1100°, 1200°, 1300°, 1400°, 1500° and 1600°C, respectively. The heating curve of the furnace as indicated by a platinum platinum-rhodium thermocouple was recorded on a Hoskins automatic recorder.

The burning shrinkages and porosities are shown in Fig. 1. The porosities were obtained by means of the Washburn-Bunting porosimeter.[2]

6. Discussion of the Volume and Porosity Changes.—The volume shrinkage curve shows that the material shrinks uniformly with rising temperature, but the curve shows no breaks or peculiarities corresponding to the peculiar changes that are found in the porosity curve. The porosity-temperature curve shows that the porosity decreases gradually to a minimum at 1350°C and thereafter increases. This peculiar behavior is apparently due to the gradual growth of large crystals at the high temperatures, these crystals being very dense, but being separated from one another by small cracks or interstices which grow in size with the crystals, consequently producing an increase in the porosity. It is probable that a body made from pure zinc oxide would gradually disintegrate at high temperature, owing to this slow crystallization.

DEPARTMENT OF CERAMIC ENGINEERING
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

Discussion

By E. W. WASHBURN:—During use a zinc retort body gradually changes in composition owing to the absorption of zinc oxide and the resultant body contains a large amount of this material. Zinc oxide itself, as Mr. Libman's results show, is a good refractory and it is practically certain that from the substances Al_2O_3 (introduced as fire clay) SiO_2 and ZnO a highly refractory zinc retort could be manufactured. There is also the additional possibility of being able to obtain a retort body which would be practically unattacked by the charge during operation. The principles to be followed in meeting this condition are known but in order to apply them the Phase Rule diagram of the system is required and this has not yet been worked out. The construction of this diagram offers no insurmountable difficulties and the requisite furnace equipment is on the market. If the zinc industry would coöperate in supporting research in this field some extremely valuable and fundamental scientific data would result which would enable us not only to understand exactly what happens in a zinc retort during usage but would also point the way toward the scientifically ideal retort body.

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[1] Washburn and Libman, *Jour. Amer. Ceram. Soc.*, **3**, 637 (1920).

[2] Washburn and Bunting, *Ibid.*, **5**, 112 (1922).

THE HARROP TUNNEL KILN

By W. E. Cramer

ABSTRACT

The successful application of the car tunnel kiln to the firing of electrical porcelains is described. This kiln is 321 feet long, 54$^1/_2$ inches wide inside, and has a placing height of approximately 60 inches. The ware is placed in saggers as formerly. Ware has been fired through this kiln in 48 hours—total time for heating up, soaking, and cooling. The kiln operates at cones 10, 11, and 12, depending upon the ware being fired. Natural gas is used as fuel and is supplied to the kiln through Maxon Premix burners. Auxiliary fuel oil equipment is also installed.

The tunnel kiln located at the plant of the General Porcelain Co., Parkersburg, W. Va., is a Harrop kiln of the direct fired type and is firing low tension electrical insulators, special porcelain and a general line of standard electrical porcelain. It is equipped for burning either fuel oil or natural gas or the two fuels can be used together. The kiln is so constructed that with a few minor changes in the furnaces, coal can also be readily used for fuel.

Construction on the kiln proper was started on March 4, 1921, and it was completed on July 14, 1921, at which time it was started in operation.

The kiln is housed in a Milliken fabricated steel building which is 60 feet wide and 350 feet long. This building is bolted together throughout having steel window sash, steel doors and concrete floor which makes it an ideal kiln building.

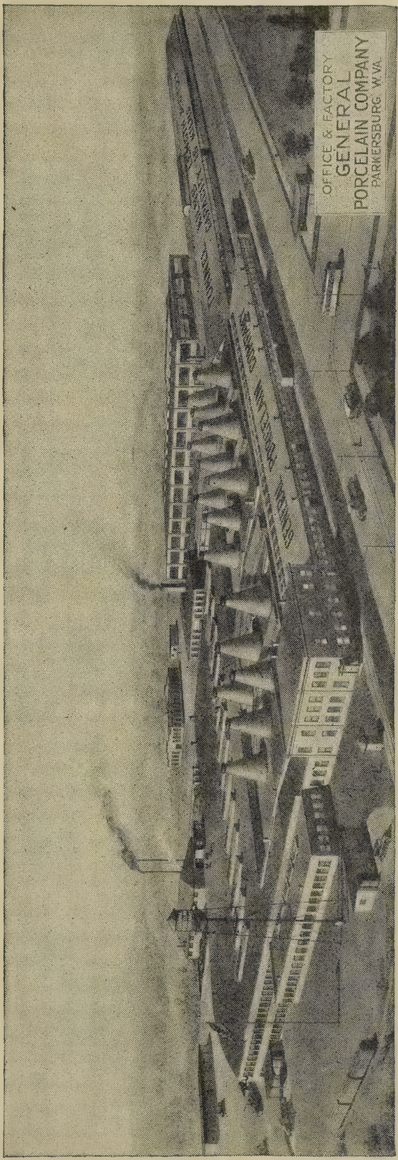
The kiln is 321 feet in length and the inside width is 54$^1/_2$ inches. The overall height is approximately eleven feet. Of the 321 feet in length, 160 feet is taken up in the heating up zone, 42 feet in the firing zone and 119 feet in the cooling zone. The firing zone includes eight furnaces, four on each side of the kiln, which are in staggered relation.

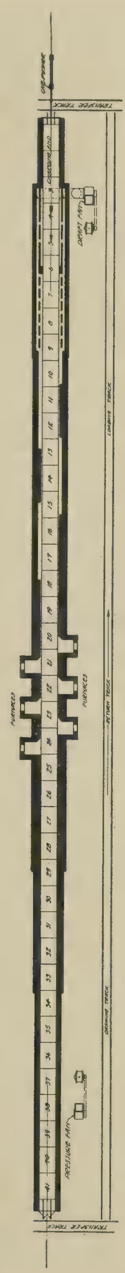
The kiln car is six feet long and 58$^1/_2$ inches in width, the effective setting space being fifty and one half inches by five feet nine inches. The metal parts of the car are protected from the high temperature by sand seals which extend the entire length of the kiln. The cars are propelled by an automatic hydraulic ram.

The burners used on the kiln are the Maxon-Premix type. They are so arranged that either gas or oil can be used and a change can be made from one fuel to the other at a moments notice. If desired both fuels could be used together.

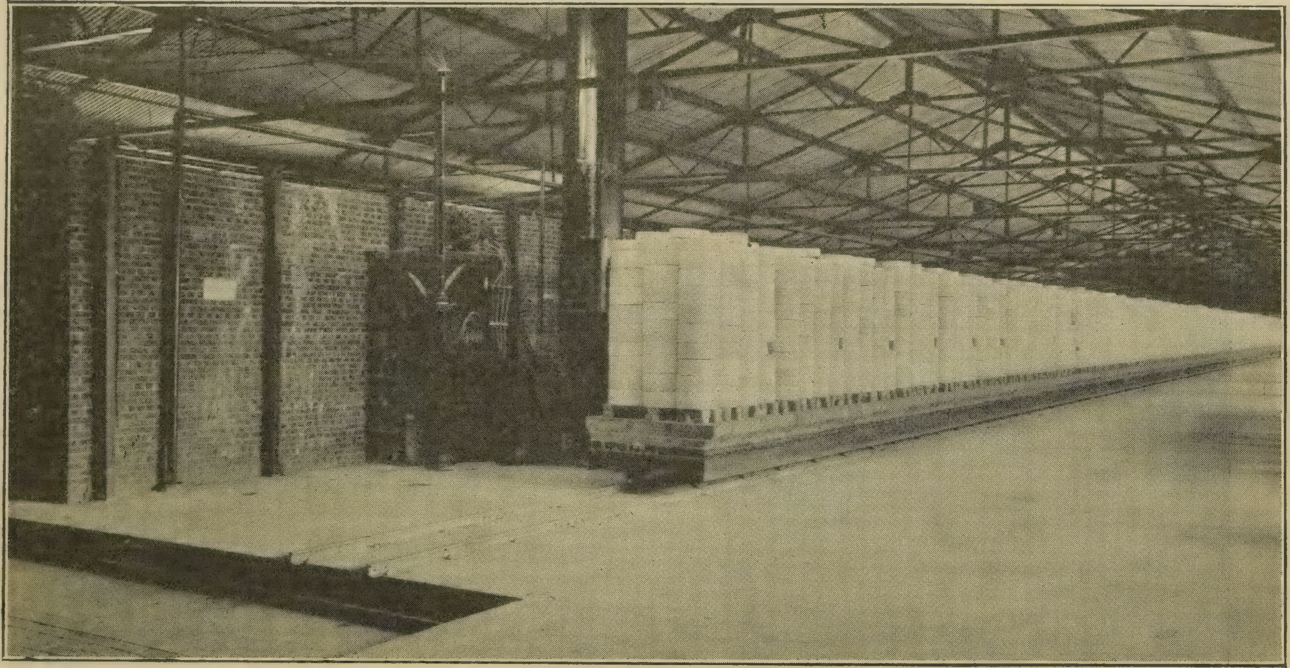
The total power required to operate the kiln is twenty-one motor horsepower. This represents the motor horsepower provided but it is calculated that only about eighty per cent of this power is used under normal operation.

There are four firemen required to operate the kiln, in two turns of twelve hours each with two men on each turn. These men attend to charging the





Typical plan.



Charging end of kiln showing loaded cars.

cars in the kiln, removing them from the kiln, and also the regulation of the heat which requires attention when there are three different firing temperatures used. That is, in firing three different kinds of ware the kiln must operate at either cone 10, 11 or 12 and be quickly changed from one temperature to another. This change can be easily made by regulating the burners and the car schedule in from one to two hours.

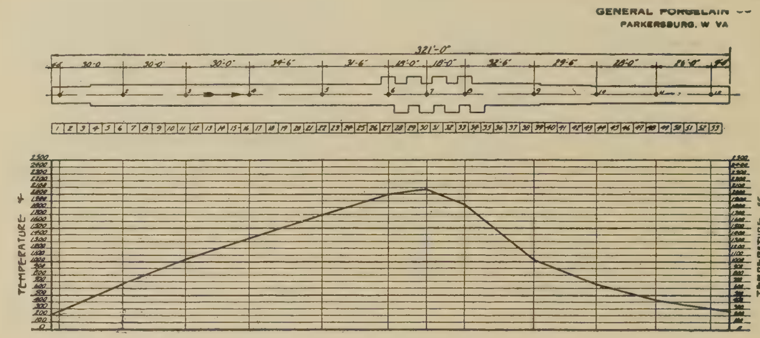
The kiln has been operated at a car schedule as fast as fifty minutes and as slow as one and three quarter hours. When operating at a one and one half hour schedule or slower it is sufficient to fire two furnaces on each side of the kiln to obtain good results, but a faster car schedule requires the use of three furnaces on each side.

The entering temperature of the kiln varies between 100°F and 220°F. The heating up curve is practically a straight line until it reaches the burning temperature of cone 10, 11 or 12. Then the temperature drops off quickly and then more slowly as it nears the end of the kiln. The discharge end temperature varies between 175°F and 350°F.

The cooling air is first drawn under the cars from the atmosphere by means of a suction produced by the air supply fan. From under the cars it is drawn through the fan and tempered with atmospheric air and then divided three ways. Part of it is forced into the discharge end of the kiln and serves for cooling the ware. The second part is forced through a flue over the entire discharge end of the kiln from where it is led down over the furnace arches and delivered into the furnaces as secondary air for combustion. The third part is circulated through hollow walls in the furnaces where it is preheated and then can be led to the burners or forced through the grates as primary air for combustion. The temperature of the air as it comes from under the cars has been found to be 340°F when the kiln was operating at cone 12. As this same air enters the discharge end of the kiln after being tempered its temperature is 165°F.

The combustion gases leave the furnaces and enter directly into the tunnel proper, travelling horizontally toward the charging end. Near the charging end they enter flues in the side walls of the kiln and are taken out by the draft fan. The temperature of these gases as they enter the stack is 350°F.

The cross-sectional heat distribution has been excellent. At times the tops of the car setting has been about one half of a cone easier than the bottoms. However, this has been easily remedied by the proper adjustment after which practically every sagger on the car received the same temperature. In August, 1921, a car loaded with one hundred and twenty five-inch saggers, every one containing cones and ware trials, was run through the kiln in order to determine the cross-sectional heat distribution. It was found that each sagger received practically the same amount of heat, there being but a quarter of a cone variation throughout the entire setting.

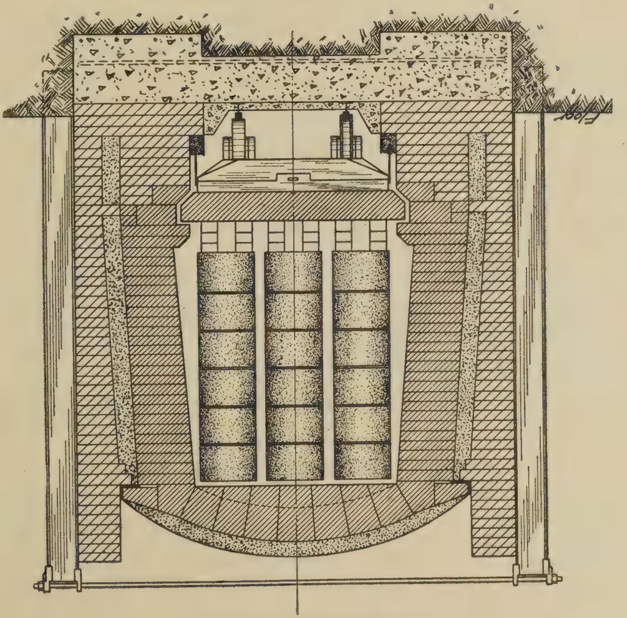


TEMPERATURE RECORD
HARROP CONTINUOUS TUNNEL KILN

DATE Aug. 30, 1921 HOUR 9³⁰ A.M. CAR SCHEDULE 1½ hrs. CONE 12 TAKEN BY W.C. Cramer

Discharging end of kiln.

The top saggers of the setting were slightly easier than the bottom saggers. Later it was found that, unlike other kilns of the car tunnel type, it was possible to maintain continuously a higher temperature along the bottoms of the setting than along the tops. This condition is undoubtedly due to the construction of the inner walls of the kiln which allows an easier passage of gases through the bottom of the setting. This is an exclusive feature of the Harrop Kiln. The car setting is three bung wide and the center bung is as well fired as the two outer ones. It was found that the same results were obtained when the saggers were set tight across the car but with a space between them lengthwise as when the setting was very loose. This again shows that there is good circulation throughout the kiln.



Typical cross-section.

The kiln was designed to have a maximum capacity equivalent to the drawing of twelve sixteen foot diameter periodic kilns per week. Using thirteen and one half inch diameter round saggers it requires seventeen kiln cars of ware for the equivalent of one periodic kiln. Thus a fifty minute schedule will give the above capacity. Using square saggers the amount of ware placed on a car can be increased by 55%. These saggers are now being made and will undoubtedly increase the saving and efficiency of the kiln.

The kiln will hold fifty-two cars in its length. Thus at an hour schedule a car will remain in the kiln fifty-two hours, twenty-six hours being used in the heating up zone, seven hours in the firing zone and nineteen hours for cooling. This gives a saving of approximately 35% in firing time over the periodic kilns.

It is interesting to note that the average weight of one car loaded with green ware ready for the kiln is slightly over ten thousand pounds, the weight of an empty car being four thousand pounds. The pusher is of ten tons capacity and to propel the fifty-two cars is required but nine thousand four hundred pounds total pressure.

A fuel test conducted during the summer of 1921 shows a fuel consumption of 195,300 cu. ft. of gas in 36 hours with a production of 35 cars. At this time six furnaces were under fire. This gives a consumption of 5,580 cu. ft. per car or 94,869 cu. ft. for the equivalent of one periodic kiln. Another test was conducted while four furnaces were under fire. Twenty-four cars were produced in thirty-six hours and 130,000 cu. ft. of gas was consumed. This is 5,416 cu. ft. per car or 92,972 cu. ft. for the equivalent of one periodic kiln. Meter readings taken during the month of November, 1921, show that the average gas consumption per hour on an operating schedule of one hour and twenty minutes is 4,200 cu. ft. of gas. This shows a considerable saving over the periodic kilns.

During the five and one half months that the kiln has been operating it has been found that there is a saving in labor amounting to the elimination of one man in placing and one man in drawing the equivalent amount of ware in a periodic kiln. The odd work around the kiln is practically the same as around a periodic kiln. However, there is the elimination of maintaining the bags, cleaning out the flues and building up the doors.

There have been practically no repairs on the kiln since it was started. One of the thermocouple welds broke but it was rewelded and replaced. Twice through carelessness it was necessary to shut the kiln off for several days. One time the fireman went to sleep and let the cars stand too long, resulting in a wreck. From the time the kiln was shut off until it was back up to temperature it was but eighty-four hours, during which time the temperature did not fall below 800°F. Another time through careless regulation of the burners a bung of saggers was caused to fall, thus requiring another short shut-down.

The kiln has shown its advantages over the periodic kilns. First of all it produces a uniformly fired product which is impossible in the periodics. It has a large fuel saving over the periodic kilns. It also has enabled a lower individual labor cost due to the fact that all placing and drawing is centralized and much easier than in the other kilns. Finally it has proved a pacemaker for the entire plant. That is, when the tunnel is operating at a certain schedule the other departments know that they have to handle a certain quantity of ware in order to keep up.

The installation cost of the kiln was considerably less than the cost of the number of periodic kilns necessary to give the same production.

Due to business conditions the kiln was closed down the latter part of December, 1921, for a couple of months. Upon cooling a close inspection was made of the kiln. It was found that but few small cracks had developed on the outside of the kiln as a result of cooling. The inside of the kiln was in perfect condition after having been in operation five and one half months. It was particularly noticeable that the expansion joints had functioned perfectly.

COLUMBUS, OHIO

THE CONTROL OF GLAZE-FIT BY MEANS OF TENSILE TEST SPECIMENS[1]

By F. H. Riddle and J. S. Laird[2]

ABSTRACT

The selection of a suitable glaze for a particular body by usual inspection of a field of glaze trials is not sufficiently precise, and gives no indication of slow crazing tendencies.

A new method of selecting glazes depends on the effect of a glaze on the strength of a porcelain tensile test specimen. The best fitting glazes increase the strength while poorer ones decrease it. Glazes which craze weaken the specimens very markedly. Results obtained with various glazes on one fire porcelain are given.

Introduction

When a glaze is selected by a systematic study of a tri-variant system, it is found as a rule that within a field of considerable area the glazes appear equally suitable, that is, the composition may be varied considerably without developing crazing, shivering, under-maturing or over-firing. The selection of the best glaze within this field has been largely a matter of judgment, and the best glaze could not be assumed to be the one most nearly central in the field of good glazes. It is frequently the case that a glaze which appears satisfactory when newly fired will develop crazing on standing. This is particularly troublesome in the case of bright glazed wall tile which have an unfortunate habit of crazing anywhere from a month to several years after being cemented up in a wall, even though they may have shown no signs of crazing when newly fired or even when stored in air for a long time.

Attempts have been made to devise tests which would indicate quickly any tendency for an apparently suitable glaze to develop crazing. The tests have usually involved subjecting the specimens to rapid variations in temperature, much wider than those to which they would ever be subjected in use. These methods while of value for the particular products for which they have been devised are not of very general applicability.

A new direct method for comparing different glazes as regards fit has been devised in this laboratory, based upon the effect which a glaze exerts on the strength of a porcelain tensile test specimen.

Preparation of Specimens

Test specimens of diameters 0.4–0.5 inch are used, similar to those used in the tensile testing of metals, modified as necessary on account of the difficulty in loading a material of the degree of brittleness of porcelain.

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[1] A contribution from the Research Laboratories of the Champion Porcelain and Jeffery-Dewitt Insulator Companies.

[2] Received April, 1922.

They are formed by turning in the green state, and after glazing and firing are broken on an ordinary cement testing machine, as described in detail in an article, "The Determination of the Tensile Strength of Porcelain."[1] The preparation of the specimens differs from that of test specimens for determining the tensile strength of porcelain bodies in that they are glazed all over (except the ends) while at least the central portions of the tensile strength specimens are left unglazed.

A number of specimens are made up from one body, glazed with the various glazes to be compared and fired together all in the same sagger when possible and in a large kiln. At least ten specimens glazed with each glaze should be prepared and tested.

Effect of Glaze on Strength of Specimens

The glazing of a small porcelain object such as one of these test specimens may (*a*) materially increase, (*b*) have little effect on (*c*) markedly decrease its breaking strength. These effects appear to be determined by the degree of success with which the glaze has been fitted to the body.

Thus, in the following series of tests the composition of a particularly good one-fire porcelain glaze maturing at cone 16–18 was modified by the addition of increasing amounts of a certain ingredient, so that while the maturing range of the glaze was not affected noticeably, crazing was developed with the higher members of the series.

The test specimens were taken from a large batch made mechanically, *i. e.*, blanks were cut from pugged one-inch rolls, and turned to a definite size. All the specimens were fired in one sagger in a commercial kiln. Each result is the average strength of several specimens.

TABLE I

SERIES OF CONE 18 GLAZES WITH INCREASED CRAZING TENDENCIES

Glaze used	STRENGTH Lbs. per sq. in.	Remarks on glaze
No Glaze	8,890	......
Glaze 255	10,245	Standard
Glaze 255 A	9,135	Very good
Glaze 255 B	4,338	Bright, but distintly crazed
Glaze 255 C	3,592	Bright, badly crazed
Glaze 255 D	3,437	Opaque, crazed

The falling off in strength with the development of crazing is very marked, dropping to only one-third with the poorest glaze. A marked decrease in strength is, however, shown by glaze 255 A, which in appearance is equal to 255, and from which it differs in chemical composition by only 1.25%.

[1] Riddle and Laird, *Proc. A.S.T.M.*, **21**, 1050–56 (1921). Riddle and Laird, *Jour. Amer. Ceram. Soc.*, **5**, 385 (1922).

The following table shows results with one-fire cone 13 porcelain with various glazes.

TABLE II

Glaze no.	TENSILE STRENGTH Lbs. per sq. in.	Remarks on glaze
22	7,520	Good bright glaze
16	6,954	Good bright glaze
691 D	6,590	Somewhat pinholed
665	5,710	Immature, mat
666	2,052	Crazed, immature

Table III gives results with a number of cone 18 glazes none of which showed crazing by usual inspection but which showed marked differences by these tests. It may be noted that the glaze selected as a result of these tests has proved extremely satisfactory and reliable for use on spark plugs, the tensile strength tests being confirmed by impact tests. Glaze No. 666 was very white and of high covering power but weakened the body to which it was applied.

TABLE III

Glaze no.	STRENGTH Lbs. per sq. in.	Remarks on glaze
644	10,876	Good, slightly vesicular
255	10,324	Good, slightly eggshell
665	10,178	Very good
649	9,779	Poor, vesicular
653	9,622	Very good
647	9,622	Good
646	9,578	Poor, vesicular
648	9,454	Poor, eggshell
652	9,382	Good
664	9,200	Poor, mat
650	9,184	Good
645	9,033	Poor
651	8,973	Good
654	8,632	Good
655	8,432	Good
666	8,119	Very good
663	7,552	Poor

Conclusions

There can be no question as to the intimate relationship between the fit of the glaze and the strength of small glazed porcelain objects such as spark plugs, or with one or more small dimensions as rods, tubes, plates, etc. This relation probably holds true to a considerable extent for porcelain objects of any size or dimension, as for example high tension insulators. Failure of the glaze to fit, especially when the fit is so poor that crazing develops, produces strains in the surface of the porcelain so that failure occurs under a much smaller external load than when the porcelain is free from such strains. On the other hand proper selection of a glaze results in a strength notably greater than that of the unglazed ware, an increase which can not be referred with one-fire porcelain to increased vitrification of the body due to soaking in of the glaze.

No experiments along this line have been made with semi-porcelain or the unvitrified bodies used in bright glazed wall tile, but it seems probable that in these cases also this method could be successfully used in the selection of glazes.

DETROIT, MICH.

DISINTEGRATION OF SODA LIME GLASSES IN WATER[1]

By Arthur E. Williams[2]

ABSTRACT

Soda lime glasses have been treated in water at temperatures below boiling point, at boiling point, and up to 25 lb. pressure in an autoclave. Effects produced are illustrated with photographs and show that glass disintegrates, *i. e.*, cracks, spalls, and loses weight when treated at any temperature used. The rate of disintegration depends upon time, temperature, composition, and heat treatment of glass surface during forming, the latter factor apparently affecting considerably the tendency to spall or chip.

Treatment given glasses conforms in many ways to treatment glass receives in service, either when sterilized when used for food packing or continued washing and sterilizing as when used for delivering or serving food daily. The relative endurance of glasses may be studied by the methods used, and standard methods of testing based upon them can be worked out. An article must stand at least six hours in boiling water without apparent disintegration or chipping to be of good quality.

Spalling always appeared on the exterior only of pressed or blown ware. Disintegration of the glass is cumulative with time of treatment whether it be periodic or continuous treatment. Treating glass in hot water with increasing pressures does not seem to give greatly increased disintegration as the temperature and pressure rises.

Surfaces of blown or pressed articles are shown to be laminated rather than smooth and impervious.

Introduction

Glass used for the daily delivery or serving of food and for the packing of food must stand repeated washing and sterilizing or several hours continued sterilization. Although glass is being made which stands these requirements in a satisfactory manner, there are also many cases where the life of the article is short, or it fails to endure the increasingly severe conditions being required of it. The following tests have been made to develop a means of determining the factors affecting the life of glass articles in service. Some very significant facts have been observed.

These experiments were confined to the treatment of soda lime glasses in distilled water at temperatures below boiling, at the boiling point, and in boiling water at pressures above atmospheric pressure.

Photographs illustrating some of the disintegrating action observed in the experiments are shown herewith. A brief description and discussion of these will be given previous to correlating the results.

Action of Water at Temperatures below Boiling

Figures 1, 2, and 3 show the results of immersing large battery jars in water at about 60°C for two months. The interior of these jars contained no water but held a few dry samples of sheet glass, the water surrounding the jars to about one inch from the top. Cracking and spalling on the jars

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[1] Glass Division, St. Louis Meeting, Feb., 1922.

[2] By permission of the Director of the Bureau of Standards.

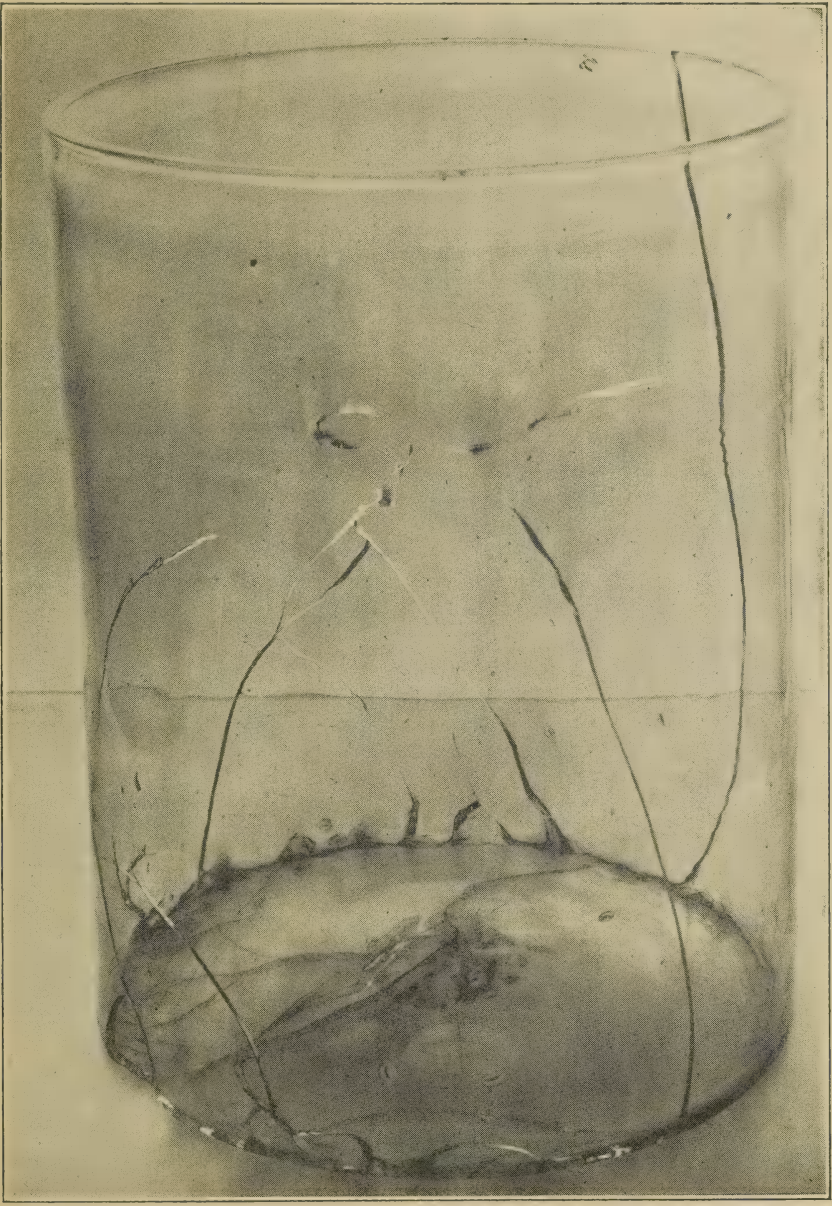

FIG. 1.

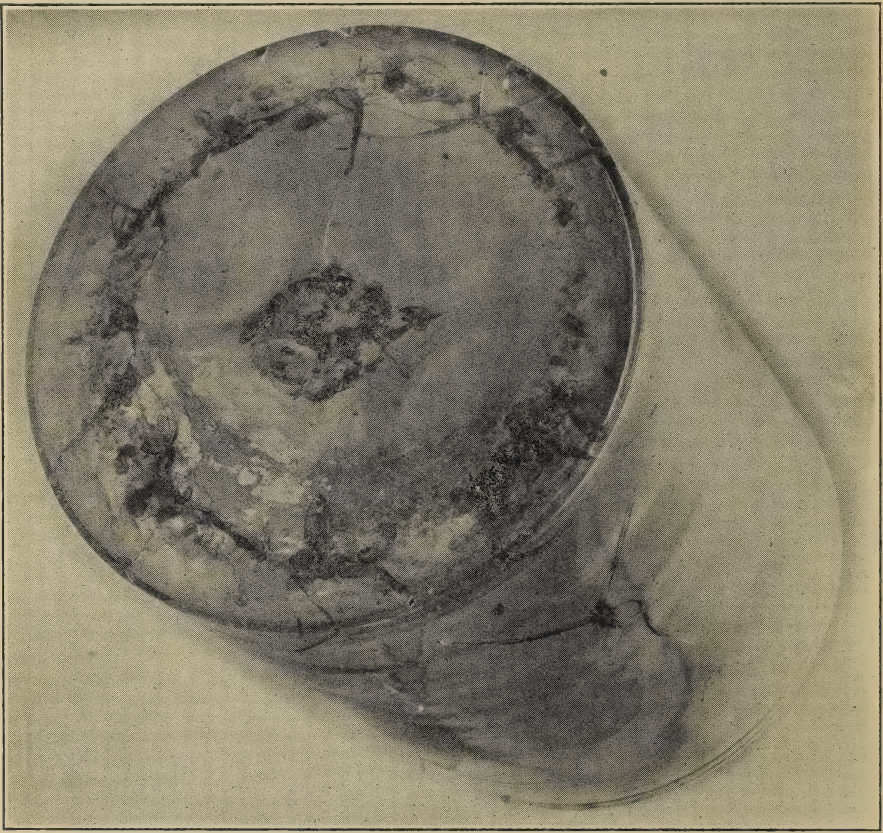

FIG. 2.

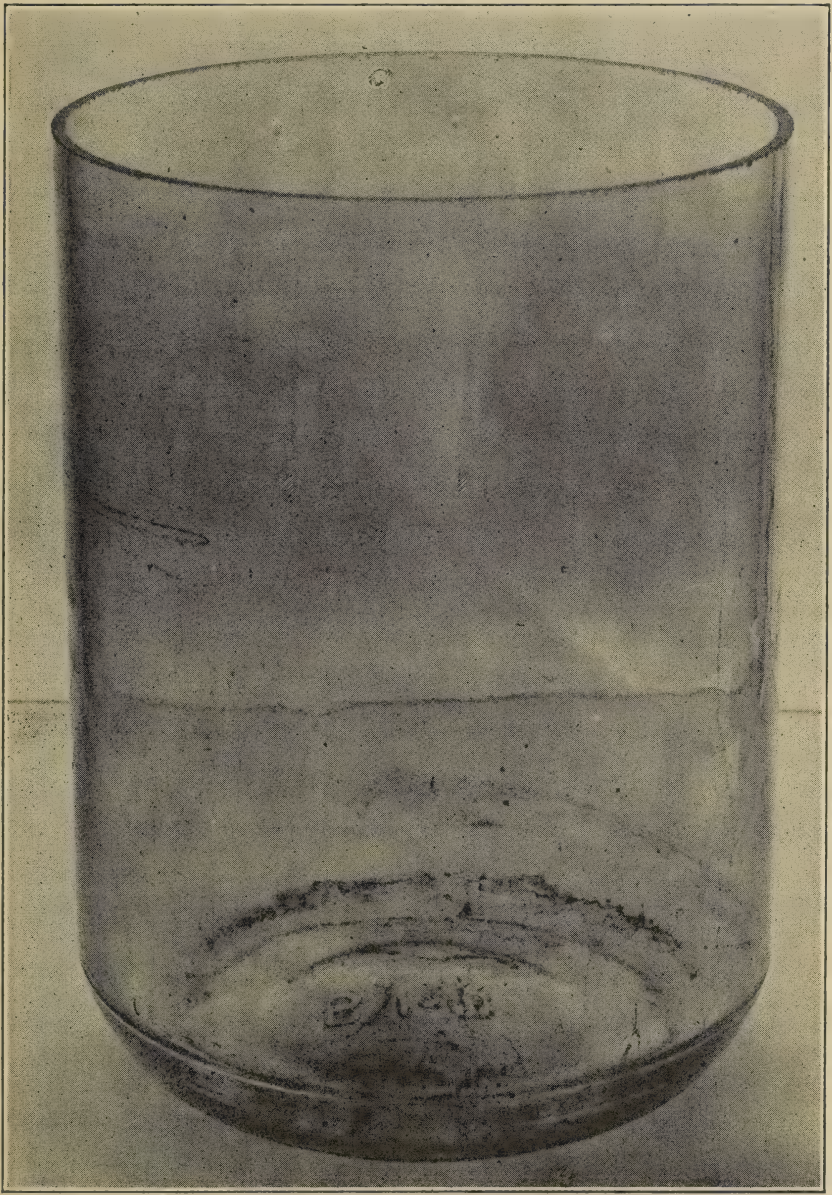

FIG. 3.

shown in Figures 1 and 2 began to appear after about two weeks' immersion. The cracks grew larger continuously and the spalled areas increased with time of immersion. Figure 3 is a battery jar of different composition and make, which was exposed to the same conditions as those shown in Figures 1 and 2, but did not give any evidence of cracking or spalling.

Action of Boiling Water

Figure 4 illustrates the effect of six hours and twelve hours continuous boiling on two types of commercial soda-lime tumblers. Tumblers 1 and 2, Fig. 4*a*, made of the same glass have been boiled six and twelve hours respectively, and illustrate what should be expected of a glass of good enough quality to warrant a reasonable life in service. Tumblers 3 and 4, Fig. 4*b*, treated in the same manner illustrate a glass which cracks in washing and of low mechanical strength. This latter glass contains but 5% of alkali earth oxides and less than 70% of silica which should be considered a glass of very poor composition.

Continued boiling of these articles would have produced a continuous increase in disintegration. This disintegrating effect is cumulative in action, in that periodic boiling for short intervals will show very similar results to a continued boiling for an equal length of time. Tests on a number of makes of tumblers and bottles show that a very great variation in the degree of disintegration may be obtained, some glasses being much more stable than the best shown in the illustrations.

Boiling Water at Pressures above Atmospheric

A distinct increase in the amount of disintegration produced for a given length of time is shown with temperatures of water increased above the boiling point. Figures 5 and 6 are photographs of tumblers and milk bottles treated in an autoclave at 0, 5, 10, 15, 20, 25, 30, and 50 pounds steam pressure for a period of 6 hours. While the effects of the treatments do not seem to increase in the same ratio as the pressures, the depth as well as the area of the spalls increases with pressure or extended treatment. Prolonged treatment results in a breaking up of the article. Six hours treatment at 5 pounds pressure is equivalent to about 24 hours continuous boiling at atmospheric pressure.

It was observed that spalling was confined to the outer surfaces in all cases. Grinding the edges of pieces of glass before treating them in the autoclave resulted in greater disintegration. The interior surface of different articles was scratched and roughed by shaking with shot, water, and carborundum, after which they were autoclaved. In this case spalling was observed on the interior. This would seem to indicate that the spalling on the exterior was due in part to a rougher surface than that on the interior.

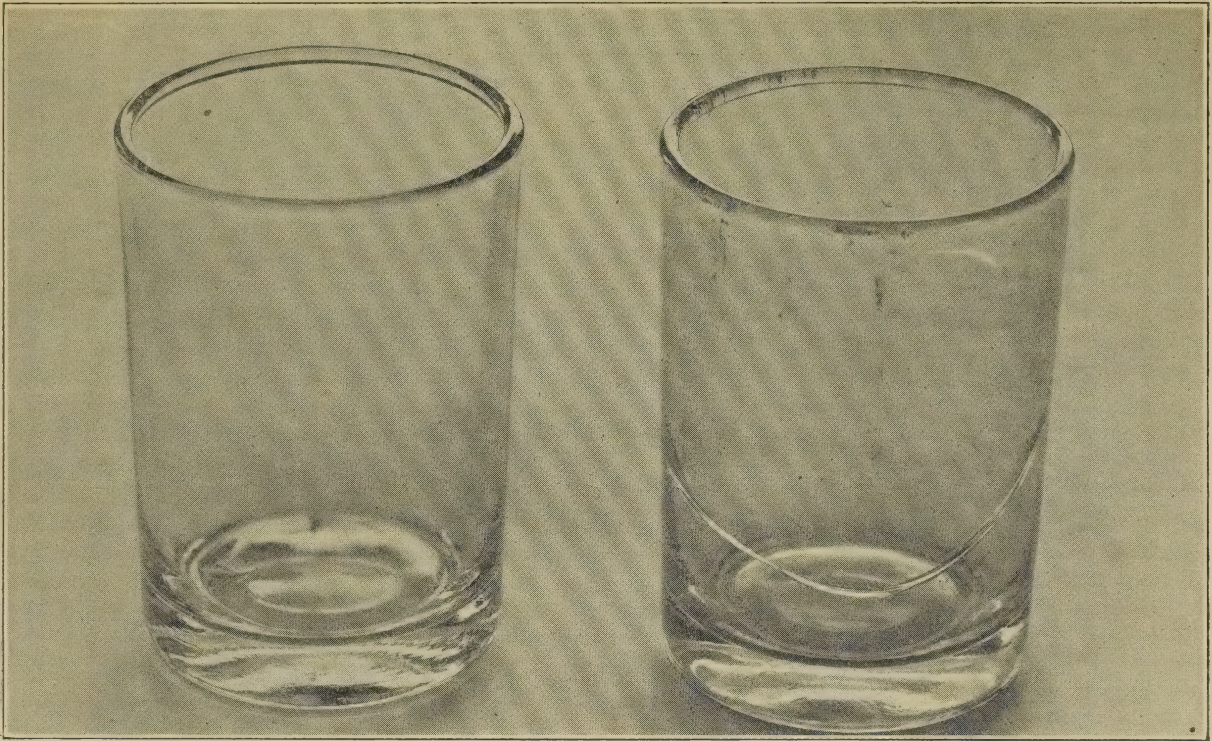

Fig. 4*a*.

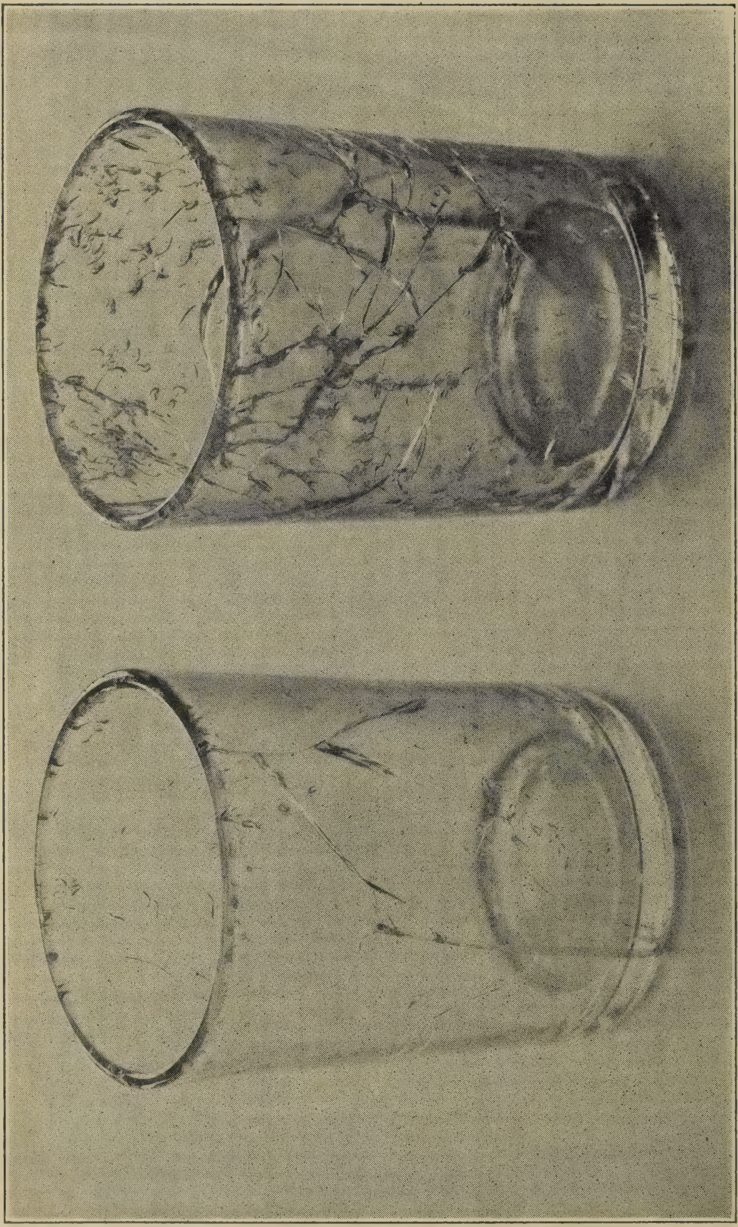

Fig. 4b.

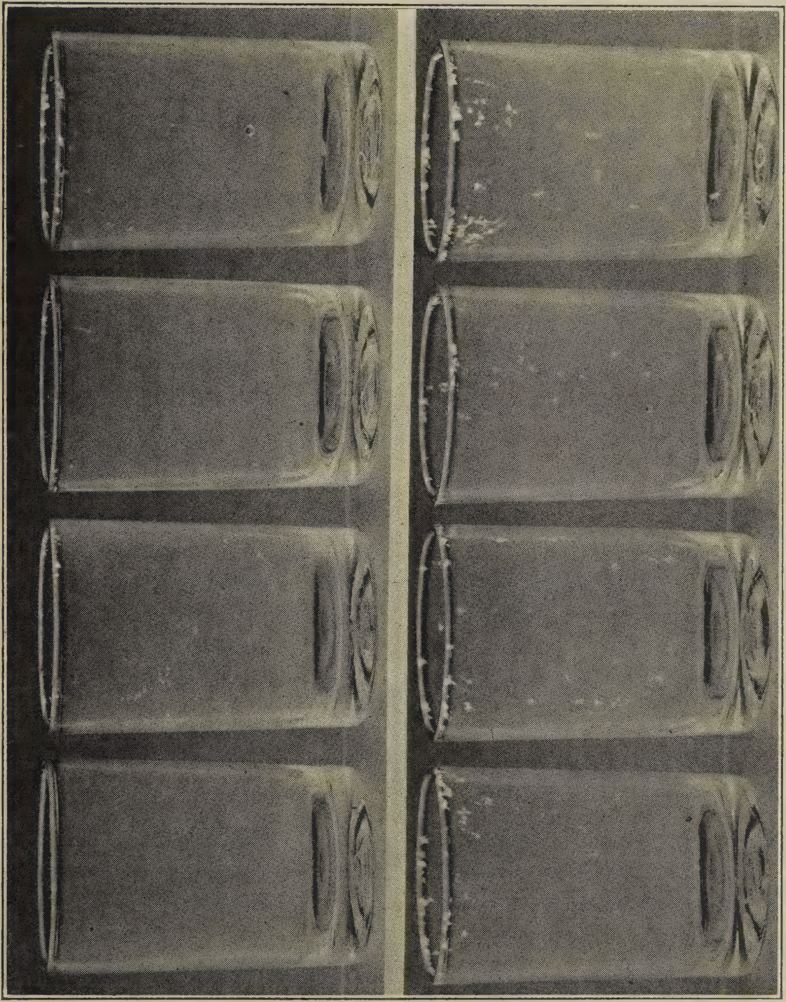

FIG. 5.

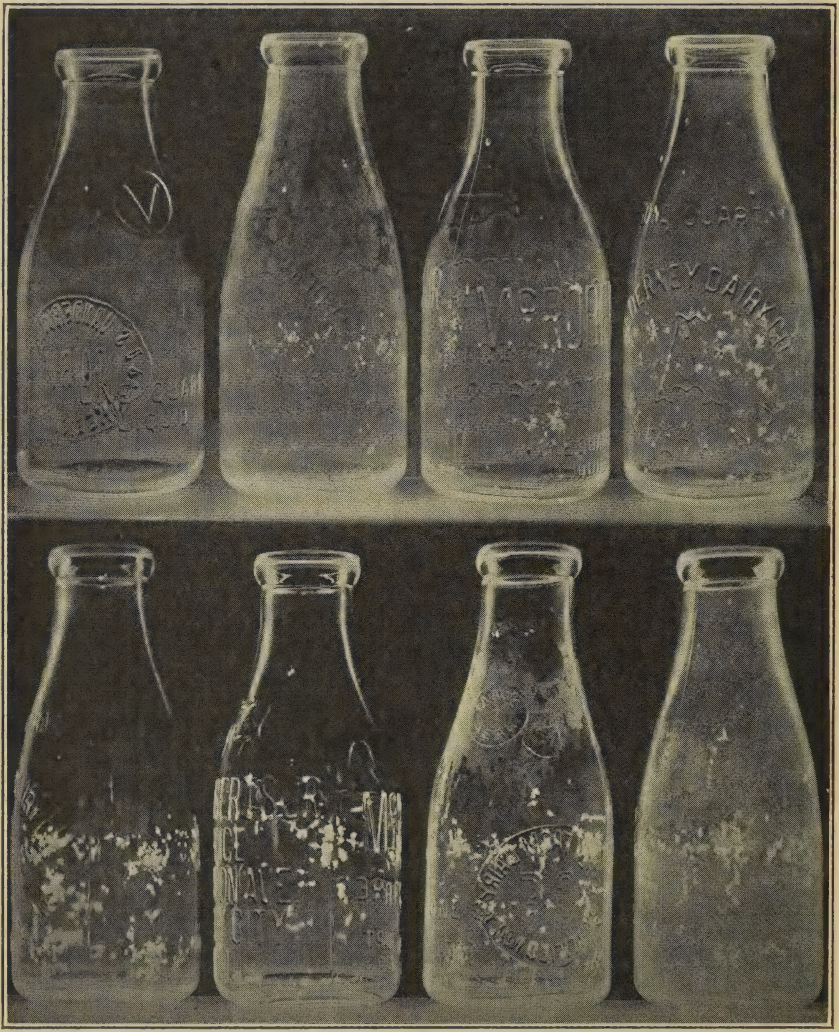

FIG. 6.

Figures 7 and 8 show the results that were obtained in an effort to smooth the exterior surface submitting the article to the autoclave tests. The deformed bottle and tumbler have been heated to the softening point (515°C) and then annealed. These articles together with those not heated were autoclaved at 50 pounds pressure for six hours. The entire absence of any spalling on the reheated articles indicates the importance of a proper surface condition. It is evident that a mere drying out of the article is not sufficient, as articles heated and annealed at temperatures at 50 degree intervals up to 400°C show no reduction in amount of spalling. Softening of the surface or a complete removal of surface strains is apparently an important factor, 450°C having been found to be the minimum temperature at which spalling ceased, which is within the temperature range required for annealing this glass. Treating a glass of poor composition in the same manner will not prevent spalling, hence the importance of both composition and surface condition.

Figure 9 illustrates a very interesting development. These tumblers were both treated in an autoclave at twenty-five pounds pressure for 6 hours and then dried at about 250°C, the tumbler on the right having been previously heated to its softening point and then re-annealed, the tumbler on the left having had no preliminary treatment. The effect is to produce on the tumbler not reheated an etched surface consisting of scale-like flakes of glassy material. These scales appear as approximately parallel curved lines which give the appearance of flow lines of the glass in pressing or blowing. This scale is found on both the interior and exterior of pressed and blown articles.

The question immediately arises, whether the glass in flowing actually tears, the scale being the remainder of the surface left after a certain amount of leaching has been done, or whether the condition is due to some other cause. Observations completed so far do not justify a positive answer.

Correlation of Observations

Reviewing the various facts observed, there is shown:

1. The chipping or spalling exhibited in the various accompanying photographs is always on the exterior, whether it be pressed or blown ware, except the type illustrated in Figure 9.

2. The effect of spalling is cumulative with increased time of treatment, in that ultimate disintegration appears whether the glass is treated in hot water periodically or continuously. Poor glasses show spalling after six hours boiling, whereas glasses having a sufficiently high silica and lime content require from 12 to 30 hours boiling to show any signs of disintegration.

3. Treatment in hot water with increasing pressure does not seem to give

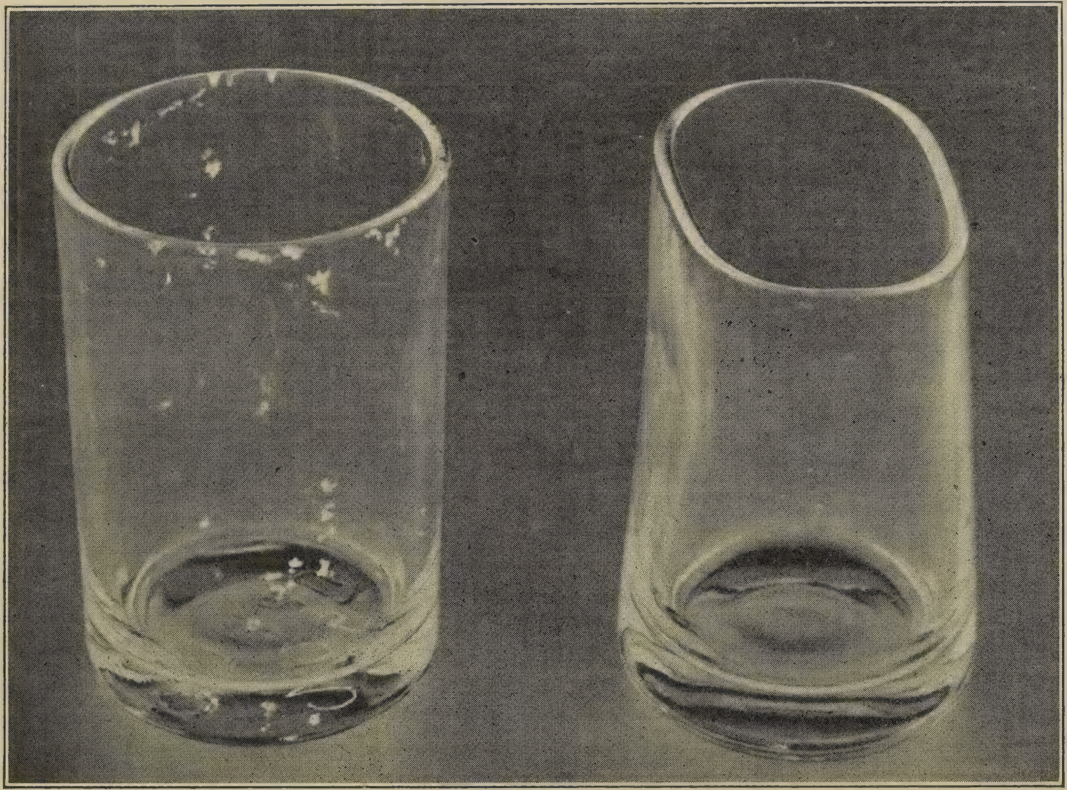

FIG. 7.

greatly increased disintegration as the temperature and pressure rise, especially on articles which are resistant to water at atmospheric pressure.

4. Although the amount of disintegration appears to be a function of the solubility of the glass the physical condition of surface is also shown to be an important factor. Reheating to the temperature (450°C) found necessary to avoid spalling in the samples shown does anneal the glass and may close minute surface cracks by softening of the surface layer. Chilling or tearing of the outer surface as compared to the inner surface, might be explained in a blown article as it comes in contact with a mold only on the external surface. Pressed ware, however, is subjected to metal contact on both surfaces and as the plunger is often water cooled the inner

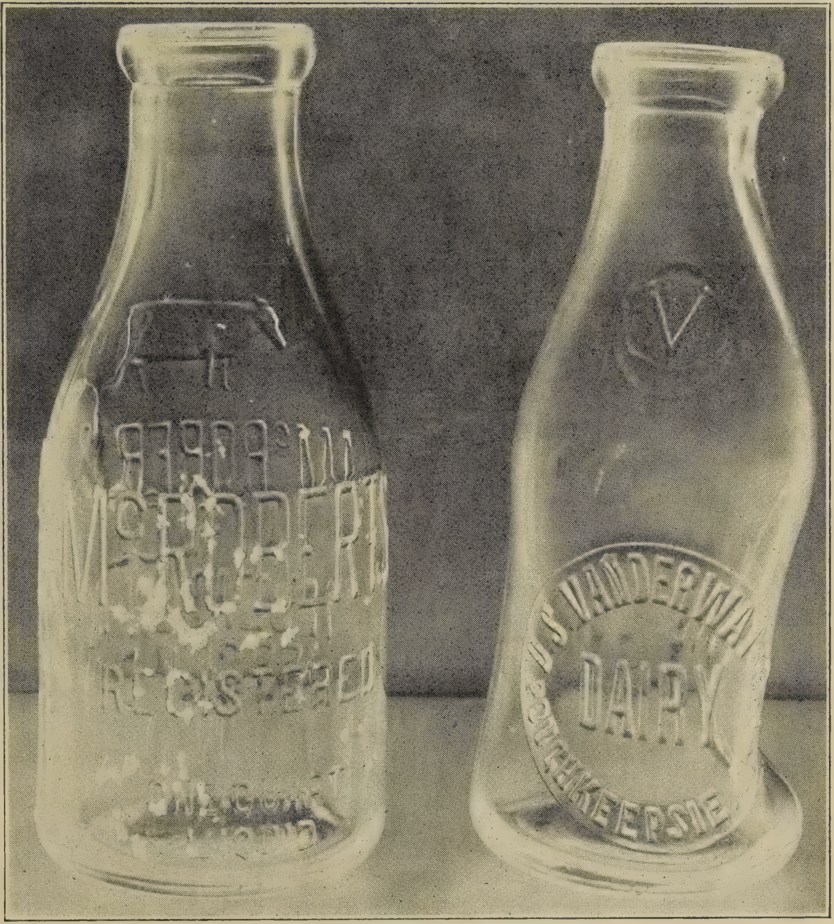

FIG. 8.

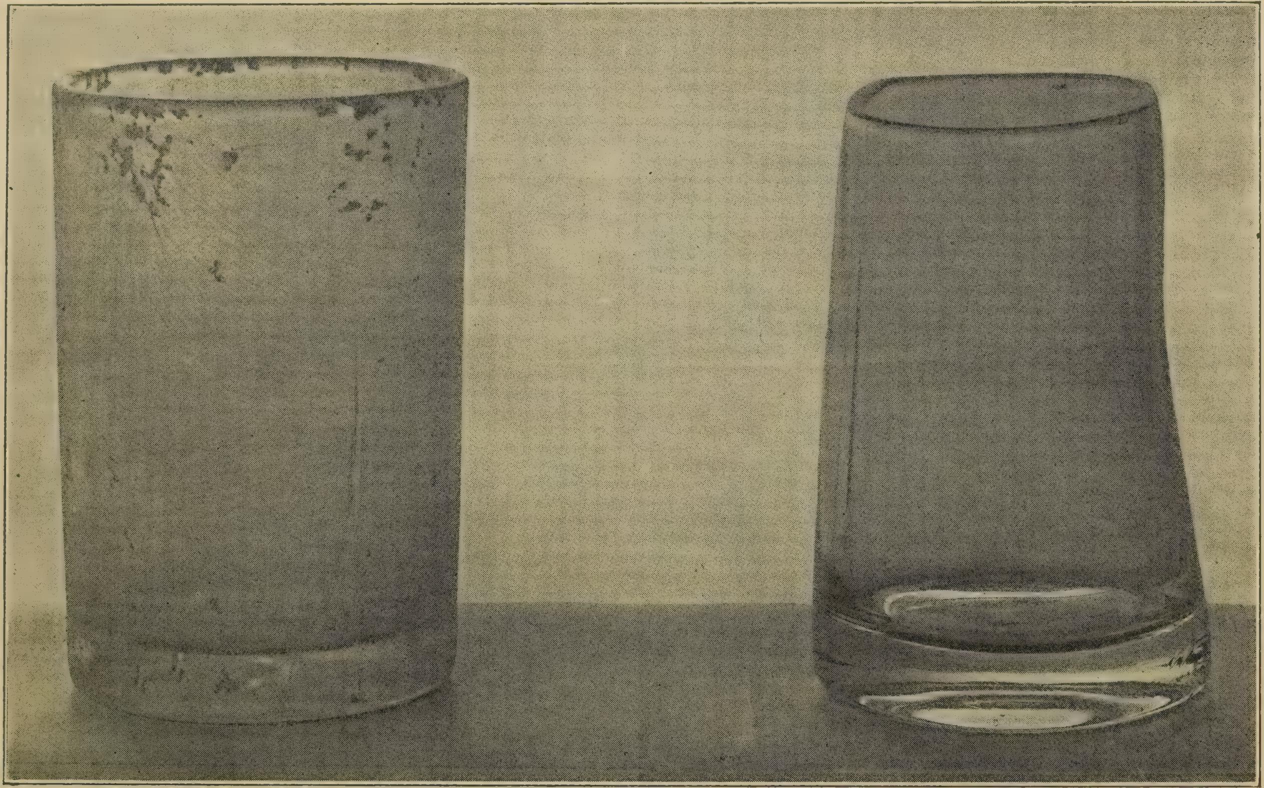

FIG. 9.

surface may be the more suddenly chilled. Just what is the physical difference between the outer and inner surface of the ware, such that spalling occurs only on the former, has not been determined as yet; but, as shown by Figure 9, both surfaces are subject to disintegration.

5. Articles which are treated for long periods in hot water will often crack. Sudden temperature changes are not needed to develop cracks, which seem to be due to strained glass. Hand finished goblets which did not crack after being filled several times with boiling water, cracked after several hours' boiling. These cracks were identified as being due to poor annealing, since they were found to be strained, and well-annealed goblets of the same make did not develop such cracks.

6. Articles which spall do not always crack, and articles which crack do not always spall. Cracking usually occurs only after moderately long treatment in water, regardless of whether the article spalled or not.

Summary

Treating soda lime glasses in water at high temperatures for a continuous period of six hours or more seems to be a very satisfactory means of indicating their resistance to the treatment certain types of ware are required to endure in service, and to indicate the general mechanical strength of the ware.

The evidence obtained is sufficient to show that both the composition and the mechanical condition of the surface are important factors. While in pressed and blown wares the interior surfaces of both kinds appear to behave similarly and the exterior surfaces of both kinds are also apparently alike, there does appear to be an important difference between interior and exterior surfaces, regardless of the process of forming.

In glasses of comparatively resistant composition, softening or reheating the surfaces seems to be the only treatment necessary to prevent spalling. Glasses having a low resistance to solution and disintegration, however, are not made immune to spalling or chipping by reheating.

The character of the results obtained indicate that the experimental methods used are capable of detecting weaknesses of a character which develop in service. It is proposed to continue the work for the purpose of collecting more evidence regarding the nature of the failures occurring.

U. S. Bureau of Standards
Washington, D. C.

NOTES ON SHIVERING OF TERRA COTTA[1]

By John L. Carruthers

ABSTRACT

Six terra cotta clays are tested for shivering as a body trouble using a white mat glaze, at cone 3 starting. One non-shivering clay and one badly shivering clay are experimented with, to produce and overcome shivering.

Causes of Shivering.—From this work and that of others which has been checked, causes are

(1) presence of *finely divided silica* in the body, from
  (*a*) highly siliceous clays
  (*b*) finely ground grog of a siliceous nature
(2) presence of soluble salts in the clay, grog, or tempering water
(3) longer firing periods

Methods of Eliminating Shivering.

(1) Use of a flux such as feldspar, *felsite,* or similar rock to overcome action of fine silica
(2) Use of coarse grog or sand
(3) Use of barium carbonate to overcome effects of salts

Shivering and crazing are the glaze and body problems that nearly all manufacturers of terra cotta or other glazed clay wares have had to contend with at one time or another. A great deal of experimental work has been done by this Company in previous years, in an effort to eliminate shivering by fitting the glazes to the body, and a small amount of work had been done toward correcting the body. The results were quite successful, with only occasional shivering taking place, probably due to variations in the body. In the summer of 1921, a great deal of shivering trouble occurred, and due to the fact that it seemed practically impossible to correct the trouble by changing the glazes, a study of the constituents of the body was undertaken, with the purpose of fitting the body to the glazes in use.

An investigation of ceramic literature shows that there is a difference of opinion among some of the investigators, as to the causes of shivering. Some of their work has been with white ware bodies, and the theories presented have seemed in accordance with some of the results of this work, hence they are included in the following references.

E. E. Gorton[2] notes that a body high in clay substance does not shiver.

H. R. Griffen[3] found that the addition of a siliceous clay to a body would cause shivering and that the addition of a feldspar to such a body would overcome the trouble. In his opinion, "shivering originates as a body failure and that the subsequent glaze shiver is a secondary reactionary consequence of the body failure." He also claims, "that while shivering and crazing are the results of strains set up due to a difference in the expansion coefficients of the body and glaze, the expansion coefficient of the glaze is always the greater. The relative strength of the body and glaze determines which shall appear, shivering occurring when the body is the weaker." He further states as his opinion, "that there are two conditions of standing between the body and the glaze, the first in vitrified bodies due to the coefficients of expansion, being brought so close together as not to produce a strain in excess of the elastic limit of the body or glaze; and the second, in porous bodies, where, while the strain is great, the powers are balanced, the factors being the relative strength and the elasticity of the body and glaze."

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[1] Terra Cotta Division, St. Louis Meeting, Feb. 28, 1922.

[2] *Trans. Amer. Ceram. Soc.*, **1,** 84 (1899).

[3] *Ibid.*, **2,** 135 (1900).

In the discussion[1] it was the opinion of some that shivering in terra cotta bodies was produced by sulfates in the clay and grog.

M. A. Coates[2] caused shivering to occur in a terra cotta body by the addition of a soluble salt. The degree of shivering was the same for either a small or large addition of the salt. The addition of a fixer such as barium carbonate overcame the trouble.

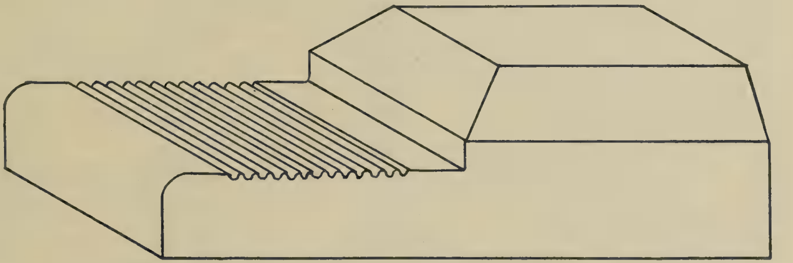

Fig. 1.

R. H. Minton[3] found that the introduction of as low as 5% of flint to a non-shivering terra cotta body, caused shivering to take place, and that shivering increased with further additions of flint.

The chief points brought out by previous investigators are the following:

(1) Shivering can be produced in non-shivering bodies or clays by the addition of a siliceous clay or ground flint.

(2) Shivering can be produced by the addition of a soluble salt to non-shivering body or clay.

(3) Shivering can be overcome by the addition of feldspar to the body.

(4) Bodies high in clay substance do not shiver.

In making the tests described later, all clays were ground to pass a 10-mesh sieve. Bodies were made by volume parts rather than by weight, so as to follow factory practice. Bodies were pugged by hand to the consistency of the regular terra cotta body. Test pieces of the shape shown in Fig. 1 were pressed in a plaster mold. This shape of piece was used because it has been our experience that shivering occurs mostly on 45 degree bevel edges and on drove or tool finish. After removing from the mold, the pieces were finished and dried. Then the test pieces were sprayed with three coats of a white mat glaze which had shivered badly in factory use. The pieces were fired in a commercial terra cotta kiln to cone 3 starting.

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[1] *Trans. Amer. Ceram. Soc.*, **9**, 520–27 (1907).

[2] *Ibid.*, **16**, 162 (1914).

[3] *Ibid.*, **17**, 310 (1915).

Formula of White Mat Glaze:

$$\left.\begin{array}{l} 0.166\ \mathrm{KNaO} \\ 0.005\ \mathrm{MgO} \\ 0.412\ \mathrm{CaO} \\ 0.417\ \mathrm{ZnO} \end{array}\right\} 0.2029\ \mathrm{Al_2O_3}\ (1.57\ \mathrm{SiO_2} + 5\%\ \mathrm{SnO_2})$$

Preliminary Tests.—Five Colorado clays, which we were using or had used, and one Indiana clay, which we knew to be successfully used in some other terra cotta plants, were each made into two bodies—one of six parts clay and four parts grog, and the other of the clay alone. Table I gives the analyses of these clays.

TABLE I

	A	B	C	D	E	F
SiO_2	58.7%	68.7%	72.8%	66.1%	66.7%	51.5%
Al_2O_3	26.6	18.2	15.9	19.8	18.3	32.9
Fe_2O_3	1.7	2.0	2.6	2.1	2.3	1.4
TiO_2	n.d.	0.7	0.4	0.5	0.8	0.1
CaO	0.1	1.4	0.7	1.0	1.6	0.8
MgO	0.8	0.6	0.6	0.5	1.2	0.4
KNaO	2.9	1.8	2.6	2.7	3.0	1.1
Ign. Loss	9.5	6.8	5.1	7.5	7.1	12.3
Total	100.3	100.2	100.7	100.2	101.0	100.5

Key to Table I:

A. A buff dense burning Indiana clay.
B. A fairly plastic buff burning Colorado clay, having a sandy feel.
C. A fairly plastic buff burning Colorado clay, having a sandy feel.
D. A very plastic buff burning Colorado clay.
E. A very plastic buff burning Colorado clay.
F. A very plastic white burning Colorado fire clay.

Results.—Bodies made with clays A and F did not shiver, while those containing D and E gave only slight indications of shivering, and bodies from B and C shivered badly. Bodies made without grog shivered worst. For further study, clays A and B were chosen from the above group in order that a comparison of a non-shivering clay and a badly shivering clay (under conditions at hand) might be made.

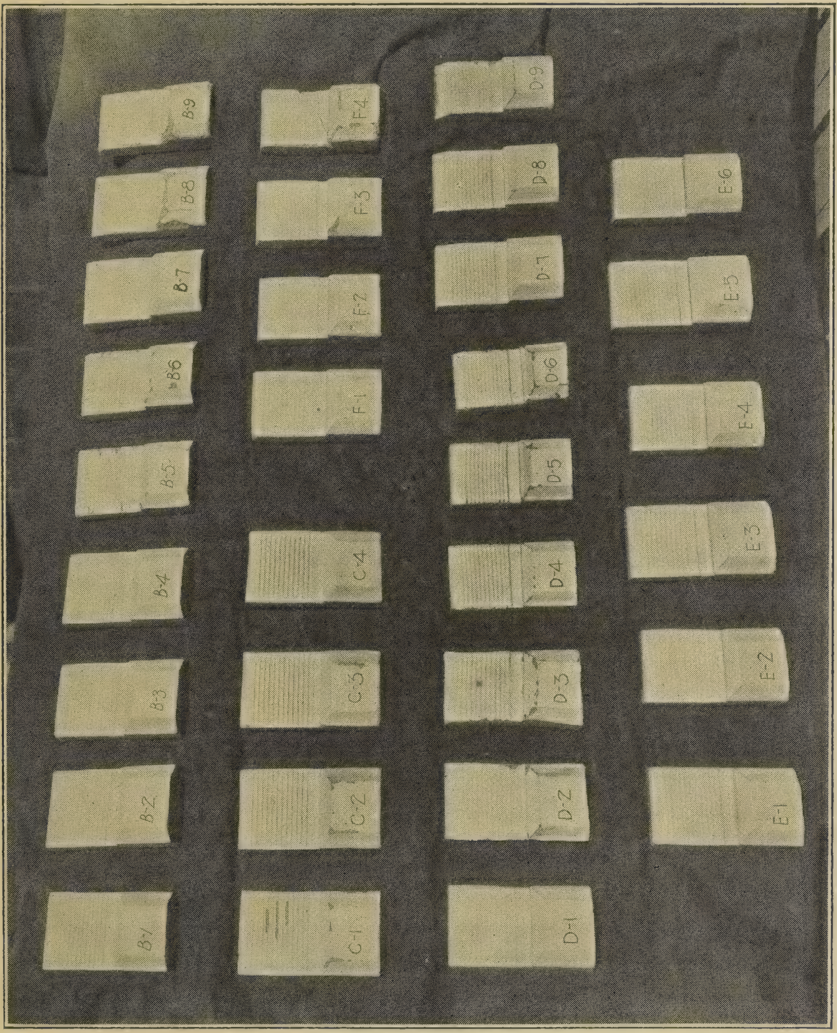
B-1
B-2
B-3
B-4
B-5
B-6
B-7
B-8
B-9
C-1
C-2
C-3
C-4
F-1
F-2
F-3
F-4
D-1
D-2
D-3
D-4
D-5
D-6
D-7
D-8
D-9
E-1
E-2
E-3
E-4
E-5
E-6

FIG. 2.

Bodies of the composition shown in Table II were made up to determine the effect of different sized particles of SiO_2. White silica sand and flint were used raw and calcined (cone 3) in this and another series but no difference was noted in the effect of either, hence only one series is shown. No attempt is made to determine any limits in this work and consequently all results are of a qualitative nature rather than quantitative.

TABLE II

	1	2	3	4	5	6	7	8	9
Clay A	6	6	6	6	6	6	4	4	5
Grog	4	4	4	4	4	4	–	–	–
Sand (10 M.)	–	1	2	3	–	–	–	–	–
Sand (20 — 40 M.)	–	–	–	–	–	–	6	–	–
Sand (150 M.)	–	–	–	–	–	–	–	6	–
Flint (200 M.)	–	–	–	–	1	2	–	–	5

Results.—Bodies 1, 2, 3, 4, and 7 showed no indications of shivering Bodies 3, 4, and 7 are very porous and open. Bodies 5 and 6 show slight shivering, and bodies 8 and 9 are badly shivered, No. 9 being the worst.

Because the bodies (in Table II) containing coarse silica particles did not shiver, the series shown in Table III was made to ascertain the effect of coarse silica, if added to a body that was known to shiver.

TABLE III

	1	2	3	4
Clay B	6	6	6	6
Grog	4	4	4	4
Sand (10 M.)	–	1	2	3

Results.—Body No. 1 shivered badly and the others much less, No. 4 showing only slight indications of the trouble. As the percentage of sand increased, the body naturally became more porous.

Previous to the last outbreak of shivering, the clay storage yard was filled with about three feet of flood waters. The water had swept over the salt coated grounds of a nearby chemical works. That some of these salts were left in the clay and grog when the piles dried out, has been established by analysis. The following tests were made to check the theory of soluble salts in terra cotta bodies, as being the cause of shivering. Fifty pounds of each of the clays and grog used in the body was soaked in a tub of water for four days, with occasional stirring. The water was evaporated down to a few gallons in each tub and then siphoned off. The waters from the different tubs were then put in one container and the bulk evaporated until about 1200 cc. was left. This water was used in the tests as indicated in Table IV.

Table IV

1.	Clay A	+ Water No. 1
2.	Clay A	+ Water No. 2
3.	Clay A	+ 2% Na_2SO_4 + Water No. 1
4.	Clay E	+ Water No. 1
5.	Clay E	+ Water No. 2
6.	Clay E	+ 2% Na_2SO_4 + Water No. 1
7.	T. C. Body	+ Water No. 1
8.	T. C. Body	+ Water No. 2
9.	T. C. Body	+ 2% Na_2SO_4 + Water No. 1

N.B.—Water No. 1—Artesian well water.
Water No. 2—Concentrated leachings.

Bodies 3, 6, and 9 were covered with a heavy coat of salt when dry. Most of this salt was brushed off before applying the glaze.

Results.—Bodies 1, 7, and 8 did not shiver. Body No. 4 shivered slightly, as in the preliminary tests. The effect of the amount of salts present in Body No. 8 was probably not great enough to cause shivering to take place. Bodies 2, 5, and 9 shivered slightly, No. 5 showing a bit more of the trouble than No. 4. Bodies 3 and 6 showed a greater degree of shivering than any of the others in this series. Increasing the amount of barium carbonate used in the body, and one other change mentioned later, has entirely eliminated shivering from our body.

Shivering in white ware has been eliminated by the use of feldspar in the body, but such practice is generally out of the question with terra cotta manufacturers because of the cost. However, to investigate the properties of the feldspars and a rock having a high feldspathic content, the following tests were made.

Table V

1. 4 parts Clay B + 1 part ground K_2O feldspar (Maine)
2. 4 parts Clay B + 1 part ground Na_2O feldspar
3. 4 parts Clay B + 1 part ground K_2O feldspar (Colorado)
4. 4 parts Clay B + 1 part ground Felsite
5. 3 parts Clay B + 2 parts Felsite (10–40 M.)
6. 3 parts Clay B + 2 parts Felsite (150 M.)

Results.—All of the above bodies, except No. 5, were free from any indication of shivering and No. 5 was not very badly shivered. The feldspar and felsite undoubtedly acted as a flux, because the body produced was much harder and more glassy, than one made from Clay B. The feldspars or felsite in the terra cotta body have overcome all shivering action produced by the presence of Clay B or other shivering clays.

Felsite is a light greenish gray rock, not as hard but tougher than feldspar. It develops some plasticity when ground fine, and burns to a hard glassy body at cone 3. It has been used in our terra cotta body for the last nine years. Previous to this work, it had been ground in a dry pan with the clays and grog of the body. It was then found in the body in particles about the size of grog. As shown in Bodies 5 and 6 of Table V, the finer the material is ground the more effective it is in eliminating shivering. The felsite is now ground in a separate mill before adding it to the body and the use of this finely ground material has entirely eliminated shivering. Felsite also aids in drying as it has a low drying shrinkage and does not warp in drying. The addition of too much felsite will cause warping in the firing process.

Analysis of felsite: SiO_2, 71.5%; Al_2O_3, 15.4%; Fe_2O_3, 2.0%; TiO_2, 0.5%; CaO, 0.8%; MgO, 0.4%; KNaO, 7.6%; Ign. loss, 2.1%; with a total of 100.3%.

A microscopic examination of some of the clays and bodies previously noted brings forth the following data:

Clay A (raw). Contains less free quartz than Clay B. Contains considerable mica, presumably muscovite.

Clay A (to cone 3). Body shows more glassy material than Clay B (to cone 3). Quartz not in solution.

Clay B (raw). Contains considerable free quartz and some hematite.

Clay B (to cone 3). No appreciable amount of quartz has gone into solution. Hematite still present.

Body No. 6 (Table V). Felsite has gone into solution with the clay and formed a bond around the quartz grains, which do not seem to have been taken into solution.

It was then thought advisable to make up the bodies shown in Table VI. This was done to see if the size of grog particle had any influence in causing shivering or eliminating it.

TABLE VI

	1	2	3	4
Clay A	6	6	–	–
Clay B	–	–	6	6
Grog No. 1	4	–	4	–
Grog No. 2	–	4	–	4

Grog No. 1—10–40 Mesh.
Grog No. 2—100 Mesh.

Results.—Bodies 1 and 2 did not shiver. Body No. 3 shivered slightly, while Body No. 4 was badly shivered, in fact the latter was much worse than a body containing unsized grog.

No effort has been made to check the statement that bodies high in clay substance do not shiver. However, the clays that did not shiver in the preliminary tests, were those having a high Al_2O_3 and low SiO_2 content, which would indicate that the clays were high in clay substance and low in free silica. Whether any clay, having a similar analysis, would not shiver under identical conditions, is problematical.

The foregoing tests and results obtained would indicate that finely divided silica in the body or clay will cause shivering and that large particles, in a corresponding amount, reduce the shivering tendencies of the body and clay. We could also expect that siliceous clays, when used in a body, will undoubtedly promote or cause shivering. Fine particles of inert material, such as grog, seem to have an action corresponding to that of fine particles of silica, though to a lesser degree. Since a good many grogs used by terra cotta companies are of a siliceous nature, it is possible that only the finely ground siliceous particles have any effect. The use of sand or a sized grog (say 10–60 mesh) will tend to overcome shivering according to the results obtained in this work, but the body is made more open and porous. The writer has heard of one company who uses sand to eliminate shivering from their terra cotta body, but because the resultant body is open and porous, such practice is questionable.

Results also indicate that the use of a flux such as feldspar or felsite will overcome shivering that is caused by fine particles of silica. Whether clays, with a high feldspathic or fluxing constituent, will act in a similar manner, is a point that might be investigated. Incidentally, there are a number of rocks of the felsite type which could probably be used in a terra cotta body to overcome shivering troubles.

Clays that have become quite dense and glassy at cone 3 have shivered badly under the conditions used in this work, and likewise open burning clays have done the same. Whether the use of a flux in the body, or the use of coarse material such as sand and grog, have any effect upon the coefficient of expansion of the body, has not been determined.

The results obtained in the work covering soluble salts agreed with that of previous investigators. It is almost conclusive that soluble salts in the body will cause shivering, not to mention other troubles that can arise. However, the use of barium carbonate has been quite effective in overcoming such troubles.

Through results from experiments, it is our opinion that the thickness of the glaze coat does not seem to have any connection with shivering. We have also found that a body with a tendency to shiver is more apt to shiver when subjected to a long firing period. No investigation has been made upon this point.

Summary.—The results of this work indicate that shivering in terra cotta bodies is caused or promoted by one or more of the following:

1. The presence of a highly siliceous clay in the body.
2. The presence of considerable finely ground grog of a siliceous nature.
3. The presence of soluble salts in the clay, grog, or in the water used for tempering.

Three methods of eliminating shivering in terra cotta bodies, if caused by one of the above, are suggested by this work and that of others. They are as follows:

1. Shivering caused by the presence of siliceous material in the body may be overcome by the use of,

    (*a*) feldspar, felsite, or rock having a similar composition, making the body more dense, *i. e.*, use a flux in the body;

    (*b*) coarse sand or grog, making the body more open.

2. Shivering caused by soluble salts can be eliminated by the use of barium carbonate.

The writer wishes to extend his thanks to Mr. George P. Fackt for many suggestions in carrying out this work, and to Mr. Hobart N. Kraner for making the microscopic examinations.

Denver Terra Cotta Co.,
Denver, Colorado

POROSITY: VII. THE DETERMINATION OF THE POROSITY OF HIGHLY VITRIFIED BODIES[43]

By Edward W. Washburn and Elmer N. Bunting*

ABSTRACT

Design and Accuracy.—The accuracy limitations of the general laboratory research type of porosimeter are discussed and the principles of design indicated.

McLeod-Gauge Type of Porosimeter.—A new type of porosimeter is described with which the pore volume of any test piece may be directly determined within 0.01–0.02 cc.

Results with Electrical Porcelain.—Tests of eight pieces of electrical porcelain indicated a porosity of 0 ± 0.01 per cent. This result was confirmed by dye penetration tests.

An Apparatus for Measuring the Porosity of Full Size Brick.—A simple and rapid apparatus for measuring the porosity of full size brick by the "General Method" (*Jour. Amer. Ceram. Soc.*, **5**, 113–16 (1922)) is figured and described.

XX. Principles of Design

75. Accuracy Limitations of the Laboratory Research Type of Rapid Porosimeter.—Of the different laboratory types of porosimeters described in the preceding paper[44] of this series, the one described in Sec. 68 is the most accurate and convenient for general research purposes and for all cases where rapidity and high accuracy are demanded, and where standard test pieces are employed. If this apparatus is to be used for bodies of low porosity, however, certain principles of design should be adhered to and even when these principles are followed as closely as practicable there will, of course, be a limit of porosity below which measurements cannot be made with this form of apparatus. We shall therefore proceed to consider in further detail the relation between accuracy and principles of design with reference to this type of porosimeter (Cf. Sec. 67).

Instead of designing our apparatus so as to make the average total error as small as possible we shall consider the design which will make the maximum total error as small as possible. The maximum error (which will on the average occur only once in 16 times) will be produced when each of the four separate errors Δx_1, Δx_2, Δx_3, and Δx_4 (*Vide supra*, Sec. 66) happen to have the same sign. The equation expressing this maximum error is therefore given by the sum of the four equations, 21 to 24 inclusive, (Sec. 66) which express the magnitude of the separate errors.[45]

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* Received May 20, 1922.

[43] Presented before the White Wares Division at the St. Louis meeting of the Society, March 1, 1922.

[44] *Jour. Amer. Ceram. Soc.*, **5**, 112 (1922).

[45] The following corrections should be made to Equations 21 to 24:

Equation 22 should read

$$\Delta X_2 = \frac{\{X[V-(R-R_0)] + 100(R-R_0)\}\,\Delta_2}{B[V-(R-R_0)]} = \frac{100+X}{1500}$$

In Equation 23, for $X\{$ read $\{X$, and for $\}^2$, read $\}^2\Delta_3$.

In writing down this sum we will, however, employ the following values for the magnitudes of the errors in the four quantities actually measured in place of the values given in connection with Equations 21 to 24; *viz.*, $\Delta_1 = \Delta_4 = 0.02$ cc. and $\Delta_2 = \Delta_3 = 0.2$ mm. In this way we obtain finally the equation,

$$\Delta X_{max} = \frac{0.02}{100 - V_F}\left[X + \frac{X(100 - V_F) + 100V_F}{75} + \frac{[X(100 - V_F) + 100V_F]^2}{7500V_F} + \frac{100X}{V_F}\right] \quad (26)$$

This equation is for a porosity bulb with a total volume of about 100 cc. and a free volume, V_F cc. ($= 100 - V_B$ cc., where V_B is the bulk volume of the test piece).

In Fig. 12 are shown the graphs of this equation for different values of x. It is evident from this figure that for each value of x there is a "best value" for V_F, that is, a value which gives the smallest maximum error. The heavy parabolic curve is the locus of these "best values." It is clear from this figure that, if this best value for V_F could be realized in each measurement, a very high degree of accuracy could be attained. It is scarcely feasible, however, to make V_F lower than about 30 cc. and if a single piece of apparatus is to serve for all types of bodies, both raw and fired, and for test pieces which are made in one standard sized mold (*e. g.*, 1 × 1 × 4″) values of V_F as large as 70 cc. will be encountered. Even with such a value for V_F, however it is evident from Fig. 12 that the accuracy attained is quite ample for all the various types of bodies except those of very low porosity. Thus even for $x = 1\%$ we find $\Delta x_{max} =$ about 0.1%. This could, of course, be reduced to 0.03% by using a test piece of 70 cc. volume (*i. e.*, $V_F = 30$ cc.) but for cases where Δx_{max} should be less than 0.1% it is more convenient to use another type of apparatus which will now be described.

XXI. The McLeod-Gauge Type of Porosimeter

76. Advantages and Disadvantages.—This type of porosimeter is shown in Fig. 13 and in Fig. 14 Y. Only a single reading is required in determining the pore volume of the test piece and a test piece of any size and any shape and of any porosity may be employed, the only condition being that the pore volume of the test piece must not exceed the capacity of the measuring tube of the apparatus. The capacity of this tube may, however, be made as large as desired. This type of porosimeter measures only the pore volume. The bulk volume must be separately determined in a mercury volumeter. The laboratory research type of porosimeter (Fig. 14 N) may be conveniently employed as such a volumeter since it is both rapid and accurate.

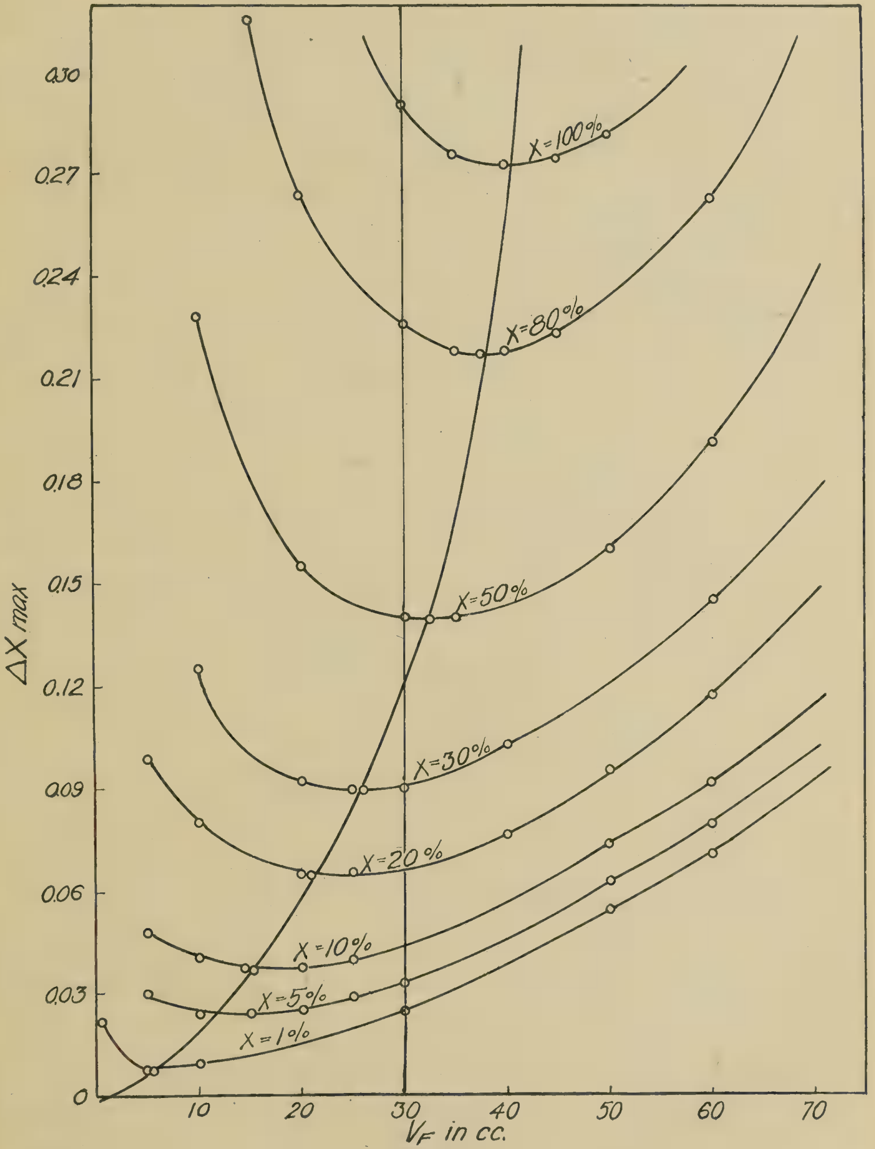
0.30
0.27
0.24
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0
ΔX max
X=100%
X=80%
X=50%
X=30%
X=20%
X=10%
X=5%
X=1%
10
20
30
40
50
60
70
V_F in cc.

FIG. 12.

The McLeod-Gauge type of apparatus will probably find its chief use in measuring the porosity of highly vitrified bodies because of the great accuracy which can be attained. This accuracy is about 0.01 cc. on the pore volume and is independent of the size and porosity of the test piece employed. The apparatus will thus be found convenient for measuring the pore volume of small pieces of porous materials of any degree of porosity since a test piece of standard size is not necessary in order to obtain accurate results with this apparatus. The reason for this is, of course, the fact that with this apparatus errors in measuring the bulk volume do not affect the accuracy of the pore volume determination.

77. Operating Procedure.—(1) Set up and connect the apparatus as shown in the photograph, Fig. 14 Y. (2) Pour 250 cc. of mercury into the leveling bulb. (3) Open stop-cock and raise leveling bulb until the apparatus is filled with mercury to a short distance above the stop-cock. (4) Close stop-cock and lower leveling bulb until mercury falls to the bottom of the porosity tube stem. (5) Raise leveling bulb to level of bottom of porosity tube and clamp it in its support. (6) Open stop-cock and when the mercury has fallen to equilibrium, release rubber bands, open the apparatus, insert the reference test piece, put the apparatus together, and again fasten it in place with the rubber bands. (7) Pour some mercury into the mercury seal. (8) Raise the leveling bulb until the apparatus fills with mercury as before. (9) Close stop-cock and lower leveling bulb until the mercury falls below the bottom of the piece. (10) Raise leveling bulb to level of stop-cock and when the mercury in the apparatus has come to rest, open the stop-cock, thus expelling the gas from the capillary tube. (11) Close stop-cock and lower the leveling bulb to the level of the bottom of the test piece. (12) Open stop-cock slightly and allow the apparatus to fill slowly with dry air. (13) Allow the test piece to soak in the dry air until equilibrium is attained. (14) Again raise the leveling bulb until the apparatus fills with mercury, close the stop-cock and lower the leveling bulb until the mercury drops below the bottom of the test piece. (15) Allow the test piece to soak *in vacuo* until equilibrium is attained. (16) Raise the leveling bulb until the two mercury surfaces are on the same level and read the volume of air in the graduated capillary tube. (17) Lower the leveling bulb to the level of the bottom of the test piece and open stop-cock. (18) Remove the reference test piece and replace by a test piece. (19) Repeat operations 7 to 17 inclusive. (20) Subtract reading obtained with the reference test piece from the reading obtained with the test piece, the difference is the pore volume, V_P, of the test piece. (21) Determine the bulk volume, V_B, of the test piece, using the apparatus shown in Fig. 16 N, or any accurate mercury volumeter.

The portion of the above procedure which is carried out with the reference test piece in place, *needs to be done only once for a given apparatus,*

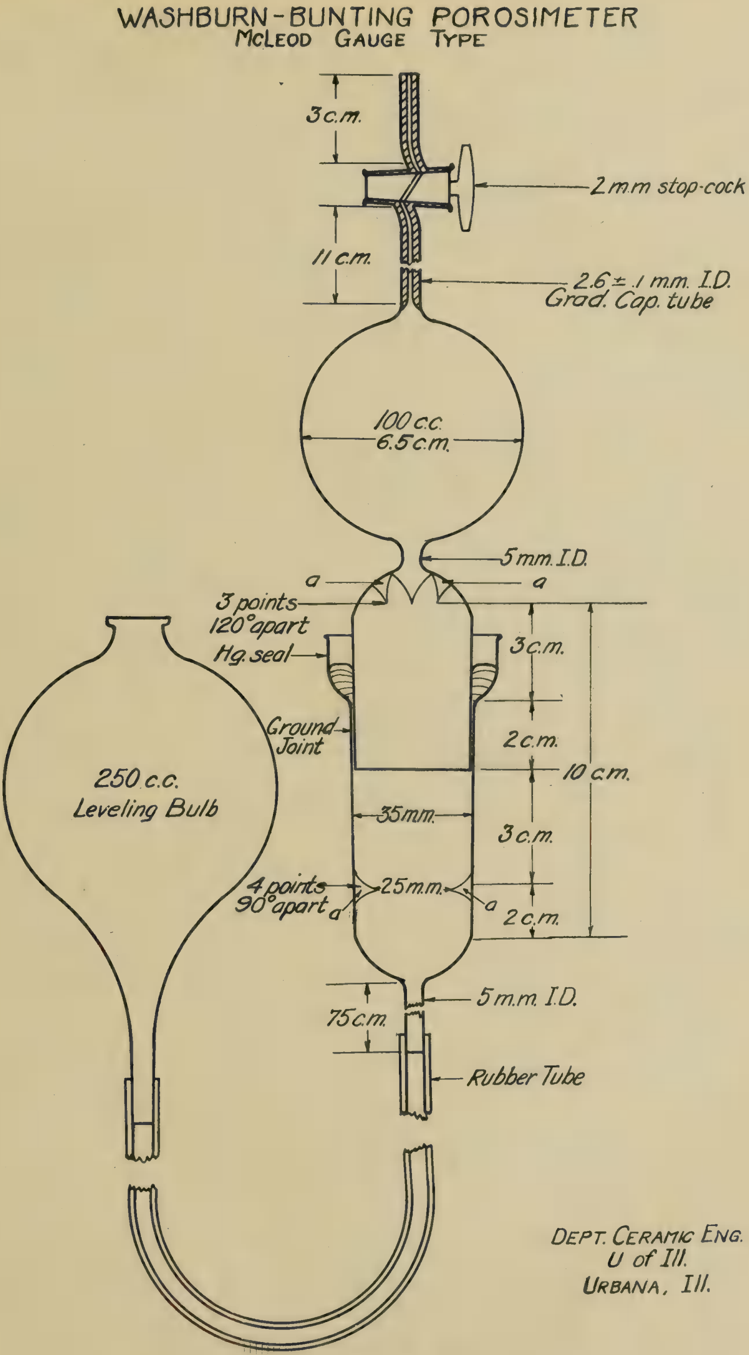
WASHBURN-BUNTING POROSIMETER
McLeod Gauge Type
3 c.m.
2 m.m stop-cock
11 c.m.
2.6 ± .1 m.m. I.D.
Grad. Cap. tube
100 c.c.
6.5 c.m.
5 mm. I.D.
a
a
3 points
120° apart
Hg. seal
3 c.m.
Ground
Joint
2 c.m.
10 c.m.
250 c.c.
Leveling Bulb
35 mm.
3 c.m.
4 points
90° apart
a
25 m.m.
a
2 c.m.
.75 c.m.
5 m.m. I.D.
Rubber Tube
Dept. Ceramic Eng.
U of Ill.
Urbana, Ill.

Fig. 13.

as the reading thus obtained is a constant for a given apparatus and a given size of test piece. As shown by the results given below the accuracy obtainable is 0.01 to 0.02 cc. on the pore volume. The bulk volume of the reference test piece should be approximately the same as that of the test piece itself, and the surface of the reference test piece and of the test pieces themselves should be approximately smooth and free from cracks, pits and other irregularities liable to retain enclosed air.

78. Calculation of the Porosity.—The per cent porosity, x, is calculated directly from the relation

$$x = \frac{100 V_P}{V_B} \tag{27}$$

The use of this simple equation is justified provided the apparatus is constructed so as to fulfill the following condition

$$\frac{{V_c}^2}{V_F} \not\gg 0.01 \text{ cc.} \tag{28}$$

Where V_c is the volume of the measuring tube and V_F is the total free volume of the apparatus when it contains the test piece.

79. Test Experiments with Electrical Porcelain.—Table X shows the character of the results obtained with (*a*) a glass test piece and (*b*) eight standard pieces of electrical porcelain. The results in column 1 show that if dry air is not employed the error due to adsorbed moisture is about 0.02 cc. The agreement between columns 2 and 3 shows that a 15-minute soaking *in vacuo* is ample. The result in column 2 in the case of

TABLE X

BEHAVIOR OF ELECTRICAL PORCELAIN IN THE McLEOD-GAUGE TYPE OF POROSIMETER

The test pieces were supplied by the General Electric Company and were of standard size (ca. 1 × 1 × 4")

Body	Nature of Surface	Cc. of gas obtained		
		1	2	3
Glass 1	Highly polished	0.09	0.07	0.07
Glass 1	Ground-glass	.16	.14	.14
P.1	As received	.15	.14	.14
P.1	Polished on fine emery wheel	.12	.11	.11
P.2	As received	.16	.14	.14
P.3	As received	.15	.14	.14
P.4	As received	.15	.14	.14
P.4	Slightly polished	.14	.13	.13
P.5	As received	.16	.15	.15
P.6	As received	.15	.14	.14
P.7	As received	.17	.15	.15
P.7	Polished on fine emery wheel	.13	.12	.12
P.8	As received	.15	.13	.13

[1] Result obtained using air from the room.

[2] Result obtained with dry air after allowing piece to soak 15 min. *in vacuo*.

[3] Result obtained with dry air after allowing piece to soak 1 hr. *in vacuo*.

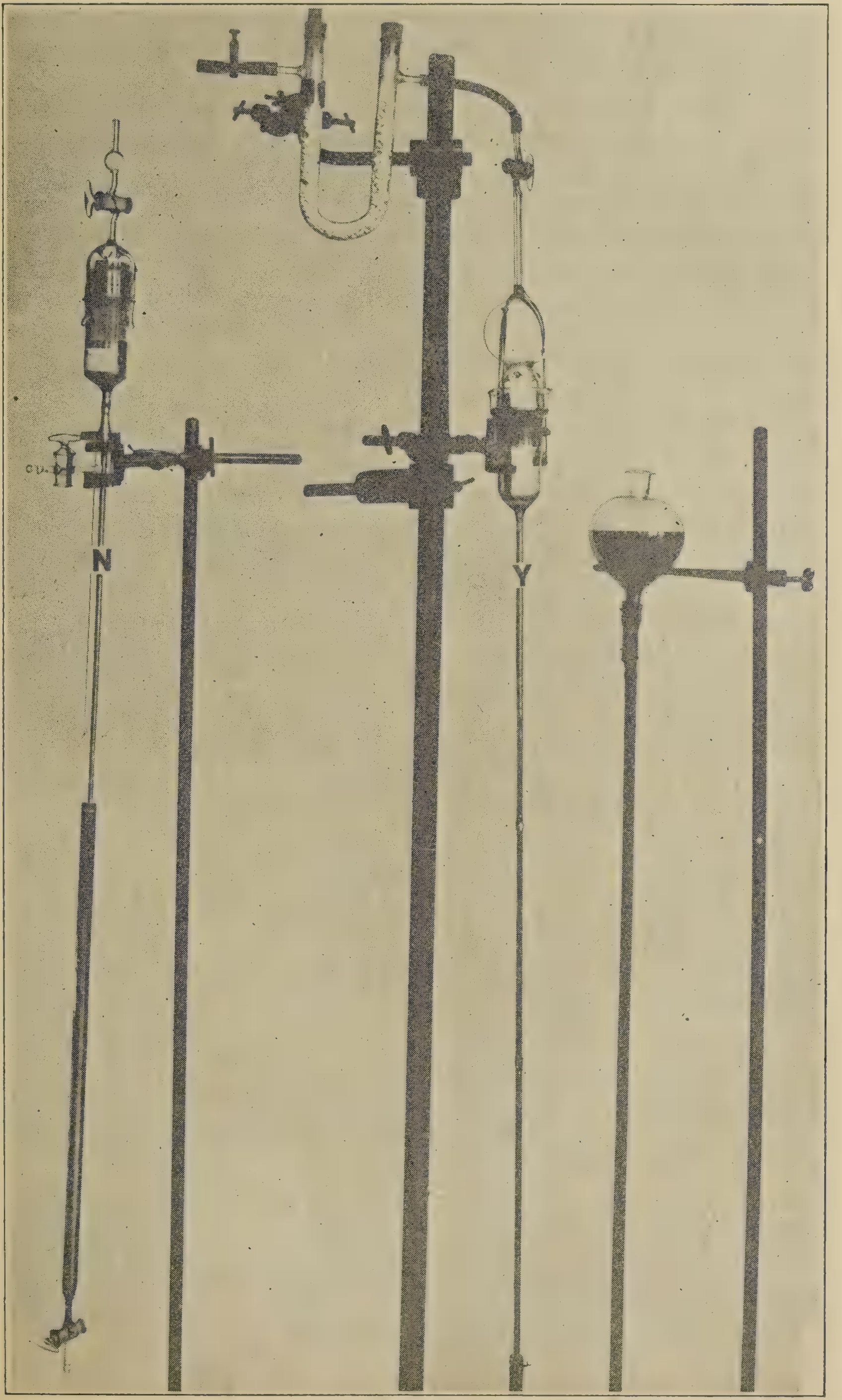

FIG. 14.

the polished glass test piece represents adsorbed air plus the air entrapped at the ground joint and at the points where the test piece touches the apparatus. This is a constant quantity.

The increase obtained when the glass test piece is given a rough surface represents the surface porosity which is also a constant for a given piece, and as the data show, is practically the same for the ground glass and for the porcelain pieces in their natural condition. Polishing the surface of the porcelain pieces naturally diminishes this surface porosity.

The results obtained show further that, within the constancy of the surface porosity (0.01–0.02 cc.), the bulk porosity of all of the porcelain pieces examined is zero. A piece of electrical porcelain of zero porosity may thus be conveniently used as a reference test piece for any of the various types of porosimeters.

80. Comparison with Water Absorption and Dye Penetration Methods.—The electrical porcelain test pieces used in the above experiments were furnished by the General Electric Company through the courtesy of Mr. L. E. Barringer. After the completion of our tests with these pieces, they were returned to Mr. Barringer and were further tested in his laboratory by the standard methods employed by the Company. These tests were carried out under the supervision of Mr. C. C. Treischel and he has given us the following report.

TABLE XI

POROSITY OF ELECTRICAL PORCELAIN TEST PIECES AS DETERMINED BY WATER ABSORPTION AND DYE PENETRATION

No.	Water absorption	Dye penetration 250 lbs. per sq. in. 12 hours	Dye penetration 7000 lbs. per sq. in. 12 hours
P.1	0.09	No penetration	No penetration
P.2	.09	No penetration	No penetration
P.3	.09	No penetration	No penetration
P.4	.25	No penetration	No penetration
P.5	.11	No penetration	No penetration
P.6	.08	No penetration	No penetration
P.7	.31	No penetration	No penetration
P.8	.09	No penetration	No penetration

The water absorption test was made as follows:

The briquettes were first dried in an oven at 120°C for 12 hours and were then weighed. After weighing they were immersed in water for 100 hours, boiling for one hour during the first, twenty-fifth, forty-ninth and seventy-third hours. At the end of the 100-hour period samples were dried and weighed and the per cent water absorption calculated from the difference between the wet and dry weights (this is our standard water absorption test at the General Electric Co.)

The dye absorption tests were as follows:

The briquettes were broken in quarters and one-quarter of each was used for the test at 250 lbs. per square inch and the second quarter was used for the test at 7000 lbs. per square inch. The dye solution was fuchsine dissolved in alcohol. The length of time during which the pressure was applied was 12 hours in each case (the 250 lb. dye test is standard with the General Electric Co., while the 7000 lbs. dye test is standard with the Locke Insulator Corporation).

With reference to the water absorption test we consider as non-porous any porcelain showing less than 0.25 per cent absorption.

It will be noted that the results of the dye penetration method, even under pressures of 7000 lbs. per square inch, agree with the results obtained with our porosimeter in indicating zero porosity for all the samples studied. The results reported on the water absorption tests are difficult to explain. They can scarcely represent any actual porosity since the other two far more sensitive methods failed to show any pore space. In the endeavor to find an explanation for the water absorption results reported by Mr. Treischel we boiled steadily for 50 hours a broken 80 gram test piece from the original lot and after drying with a cloth and weighing (to 0.1 mg.), it showed *no appreciable gain in weight.*

As the net result of the above experiments it seems justifiable to conclude that the McLeod-Gauge type of porosimeter may be recommended for the accurate and rapid measurement of the open-pore porosity of highly vitrified bodies.

XXII. Appendix

81. The "General Method" for Full Sized Brick.—A convenient apparatus for determining the porosity of full sized brick by the *General Method*[46] is shown in Fig. 15. The containing vessel is designed to take the largest size standard brick in the dry state. For smaller brick the unoccupied space may be filled as explained in Sec. 55, using glass plates for this purpose. The containing vessel may be made of any suitable non-porous material (*e. g.*, glass, metal, porcelain). The cover is a glass, metal, or porcelain plate ground so as to give an air-tight joint when greased, this method of closure being similar to that used in the ordinary chemist's desiccator. The remainder of the apparatus is mounted permanently on the cover and is easily constructed from glass tubing and a distilling flask. An ordinary water-jet suction pump is satisfactory for evacuating the flask.

The operating procedure is as follows: (1) With the brick in place, and both stop-cocks open, read the manometer, (*i. e.*, the difference in the two mercury levels), B. (2) Close stop-cock 1 and evacuate the flask F to some low pressure, P_1. (3) Close stop-cock 2 and again read the man-

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[46] See the 6th paper of this series, *Jour. Amer. Ceram. Soc.*, 5, 113–116 (1922).

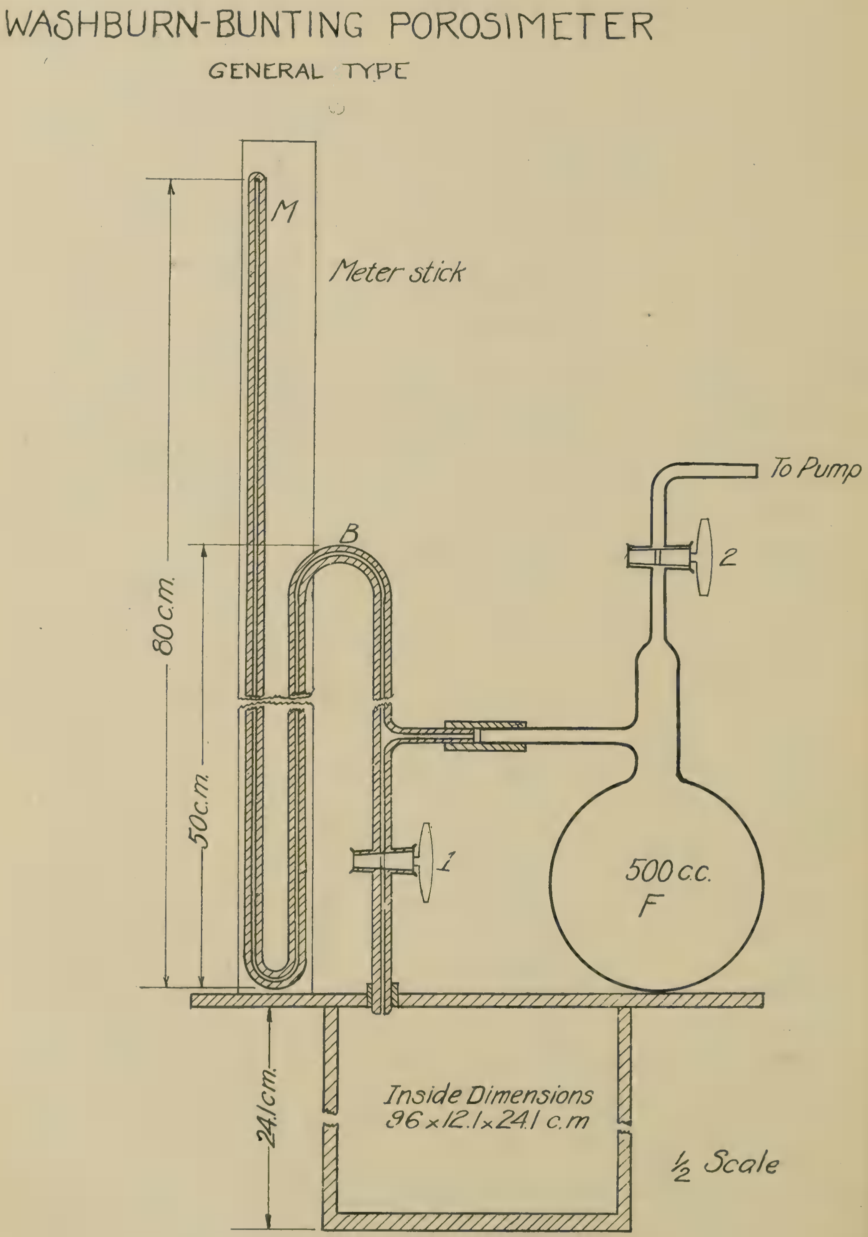
WASHBURN-BUNTING POROSIMETER
GENERAL TYPE
M
Meter stick
B
To Pump
2
80 c.m.
50 c.m.
1
500 c.c.
F
24.1 cm.
Inside Dimensions
96 × 12.1 × 24.1 c.m
½ Scale

Fig. 15.

ometer, P_1. (4) Open stop-cock 1 and when pressure equilibrium is attained, again read the manometer, P_2. (5) Calculate the per cent porosity, x_1

$$x=100\left[\frac{(P_2-P_1)V_1}{(B-P_2)V_B}-\frac{(V-V_g-V_B)}{V_B}\right] \qquad (29)$$

where V_1 is the volume of the flask F from stop-cock 2 around to stop-cock 1 and including that portion of the manometer tube from the mercury surface in B around to the side-arm leading to the flask; V is the volume of the containing vessel and that portion of the capillary up to stop-cock 1; V_g is the volume of any glass plates which may be used for reducing the free volume of the containing vessel. (Cf. Equation 14, Sec. 55.) The bulk volume, V_B, of the brick may be conveniently determined with a water volumeter of the over-flow type, the brick being first dipped momentarily into hot paraffine or rubbed thoroughly with vaseline or other similar grease, in order to close its surface pores. With unperforated bricks having straight edges the bulk volume may in most cases be computed with sufficient accuracy from the linear dimensions.

SOLUBLE SALTS AND CLAY WARES*

By Cullen W. Parmelee†

ABSTRACT

A résumé of the present knowledge of the causes and the prevention of "Scum" and "Efflorescence." It is proposed that the term "Efflorescence" be restricted to designate the surface deposits appearing because of the presence of soluble salts in the clays or burned wares and that the term "Scum" be used to describe the salts formed by the action of gases upon the wares during the drying or burning operations.

Mention is made of the formation of a surface coating upon the ware soon after the kiln is opened, sometimes not appearing until some days after the ware is removed from the kiln. This scum is readily and permanently removed by the application of water.

Such a residue was found to consist of sodium sulfate and sodium chloride. It is suggested that its formation was due to the presence of sodium chloride in the fuel and its subsequent deposition on the burned ware where it was changed in part to the sulfate by the action of the oxides of sulfur evolved from the fuel.

Introduction.—The causes and the cures for the various manifestations of these salts have been topics of lively interest among manufacturers, architects and builders for many years. A very considerable amount of literature has been accumulated which has furnished a valuable source of information. In fact, the writer feels some hesitancy in presenting this paper because he recognizes the fact that most phases of the subject have been so ably discussed by others that this cannot be considered an original contribution, but a compilation of various opinions. However, I have been surprised to find that one phase of the subject which is of considerable inportance has scarcely been noticed by writers; namely, the type of kiln scum which is of temporary character as contrasted with that which appears to be permanently burned into the ware.

Definitions.—In order to clear our way of misunderstandings due to a confusion in the use of terms, I will define those which I am about to discuss. They are: *Efflorescence:* The accumulation of salts upon the surface where they have been brought in solution and deposited upon the evaporation of the water. *Scum:* A term which is used interchangeably with efflorescence.

There does not appear to be any general agreement as to a distinction in the usages of these terms. Searle, an English writer, author of several books on ceramic topics, says that "efflorescence" is due to the formation of this deposit during drying and that "scum" is formed during the burning. In answer to an inquiry made by letter, one of your members has kindly written to me that in his study of the matter he has found the

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[*] Address before the Indiana-Illinois Division of The American Face Brick Association, at its meeting in Chicago, on Tuesday, April 11, 1922. Received July 3, 1922.

[†] Distributed by the Secretarial Department, The American Face Brick Association, 130 North Wells Street, Chicago.

term efflorescence applied to the discoloration which appears on the brick in the wall, or brick in stock piles after they have been wetted. "Scum," he says, is commonly understood by himself and his associates to be the surface deposit which is formed during the drying process.

Dr. H. Ries, in his book "Building Stones and Clay Products,"[1] uses both terms without differentiating between them. Lovejoy,[2] in an article entitled "The Use of Barium Compounds in Preventing Scum," says that there are "three distinct lines of efflorescence," one of which is "dry-house white, the common scum." In other words his practice conforms to that mentioned by one of your members. A diligent search of literature has failed thus far to find any general agreement regarding the use of the terms.

It is well for us to arrive at some agreement regarding the use of these terms since it is obvious that we cannot hope to make much progress in a discussion, if each party is using a different language.

My own feeling in the matter is that we can use the word "efflorescence" as defined in the dictionary to include all surface deposits of salts which have accumulated there through the agency of water which has brought them to the surface in solution. This term will then include those surface deposits of salts that accumulate upon raw clays in their original beds, or in stock piles and bins, all surface deposits which occur in the drying of the ware *excepting* certain examples dried with the waste heat of burning kilns, all coatings of soluble salts on masonry work in walls, piers, etc., which have originated through the solvent action of water upon materials in the clay wares or have been contributed by the mortar used, also coatings of soluble salts brought to the surface during the early stage (the water smoking) of the burning process.

The use of the word "scum" I would limit to designate all surface coatings of soluble salts which have originated through the agency of gases in the atmosphere of the drier or kiln; also through deposits upon the surface of volatile substances. Our classification will then include:

Efflorescence	Soluble salts upon clays
	Drier or dry-house white
	Kiln white—certain forms
	Wall white
Scum	Drier white due to the action of waste gases
	Kiln white with exception noted above
	Certain forms of wall white

We will now take up these items in detail discussing the causes, occurrence and proposed remedies.

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[1] Ries, "Building Stones and Clay Products," p. 312.

[2] Lovejoy, *Trans. Amer. Ceram. Soc.*, **8**, 255 (1906).

Efflorescence

On Raw Clays.—All clays contain soluble salts. That is to be expected since all clays have been formed through processes of decomposition and solution of various rocks, many of which are of types very resistant to chemical attack. English china clays which have been formed from rocks of a granitic type and are typical of the purest kind contain, according to Dr. Mellor,[1] about 0.015 per cent soluble salts. The same authority says that ball clays contain normally 0.4% soluble salts which are chiefly soluble silicic acid (15 to 20%) and soluble silicates of alkalies and alkaline earths with about 1 to 2% of alkaline chlorides and about 20% of sulfates. Ries, in his report upon the clays of New Jersey, found in testing a large number of samples which varied widely in character that the soluble salts ranged from 1.49% to nothing. The report on the clays of West Virginia by Grout states that the amount of soluble salts present varied from a trace to 1.2%. In a report on the clays of Texas,[2] Dr. Ries states that the amount of soluble salts ranged from 0.05 to 1.21 per cent.

Fortunately, the soluble salts are not all objectionable and also certain conditions interfere to prevent the objectionable ones from always exerting the maximum harmful influence.

Character.—The soluble salts present in clays are of many sorts. They include hydrated silicic acid, aluminum salts, probably most commonly the sulfate, the sulfate of iron (the writer has seen crystals of both the sulfates of iron and alumina upon the face of clay as it lay in the bank), the sulfates of lime, magnesium, and the alkalies, sodium and potassium, also the chloride of sodium is not infrequently found and it is altogether probable that this list may be very considerably extended. Of these salts, the most frequently found and the most troublesome are the sulfates of lime and magnesia.

Formation.—In studying clays, we are dealing with materials which contain particles of varying sizes, some of which are so small that they cannot be seen except with a microscope especially designed for the purpose. When matter is reduced to such infinitesimally small fractions and subjected to prolonged contact with water, it is taken into solution, more or less. This process is repeatedly occurring in our laboratory work. When we grind material for a long period in contact with water, we find that there is unmistakable evidence of a gradual solution of a small portion of the batch. Therefore, we expect to find soluble salts in all clays, varying in amount and character of course, but there, nevertheless, because of the continued solution of the finest portions upon long contact with water. This is the explanation for the observation of Grimsley and Grout[1] that the soluble salts found in West Virginia clays were unexpectedly high in alumina and silica and in some cases no sulfates could be found.

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[1] Mellor, "Clay and Pottery Industries," p. 56.

[2] Ries, *Bull. Univ. Texas,* No. **102,** p. 45.

In fact, the determination of the amount of soluble salts in clays is seriously complicated by the progressive solubility of clay in contact with water, so that the duration of the contact and the temperature are extremely important factors in such an investigation. You will find this point noted in a paper which was contributed to the *Transactions of the American Ceramic Society.*[2]

Formation of Sulfates.—Iron pyrites (ferric sulfide) is a common mineral in almost all kinds of clays, occurring in large lumps and also in finely divided particles. It is quite insoluble. If this mineral, especially the form known as marcasite, is exposed to free contact with air and moisture, it will oxidize to form the sulfate of iron which dissolves freely in water and is frequently found as a yellow or brownish yellow efflorescence on raw clay which has a sweetish astringent taste, reminding one of ink. This efflorescence sometimes occurs on ware coming from the drier and is known as "brown scum." On the burned ware, *i. e.*, of red or brown color, it cannot be readily distinguished, because it is decomposed during the burning and the iron oxide remaining will be red or brown.

The sulfate of iron formed from the pyrites in the clay will decompose quite readily and set free sulfuric acid which in turn will speedily attack the carbonates of lime, magnesia or iron which may be present and form the sulfates of these bases. This is a very ordinary method of the formation of the sulfates of lime and magnesia.

For this reason, the weathering of clays containing pyrites or marcasite, the sulfides of iron, has been a frequent cause of serious efflorescence. The remedies are either, use the clay as promptly as possible after mining, or on the other hand weather the clay for a sufficient length of time to permit the complete change and removal of the sulfides. However, this will not avail if the clay contains the carbonates of lime, magnesia or iron, since the sulfuric acid formed will attack and form the very troublesome sulfates of these bases.

Ries[3] cites the analysis of a clay freshly mined containing pyrites which showed a soluble salt content of 0.2 per cent. The same clay which had weathered showed 0.87 per cent soluble salts.

If weathering is resorted to, the clay should be spread out in a layer not over two feet thick on a hard, slightly inclined floor. This will permit the removal by natural drainage of the soluble iron salts formed. Of course, the weathering process may be hastened by spreading the clay in thinner layers and by wetting the mass thoroughly from time to time.

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[1] Grimsley and Grout, *West Virginia Geol. Surv.*, Vol. III, p. 26.

[2] *Trans. Amer. Ceram. Soc.*, **11**, 467 (1909).

[3] Ries, "The Clays of Texas," *Bull. Univ. Texas*, p. 45.

In this process, the soluble salts formed are brought to the surface during drying and then removed by the water which falls upon the surface, either as rain or from a hose. Analyses which I have before me showing the change in a clay by weathering gives the following figures:

	Before weathering	After weathering
Lime (CaO)	1.98%	1.01%
Alkalies (Na_2O, K_2O)	1.62%	0.75%

This illustrates how the change proceeds in that particular case.

Mellor[1] suggests that soluble salts in a clay may be due to the action of humic acid upon calcium carbonate which is present. Humic acid is one of the products formed by the decomposition of organic matter and, undoubtedly, it is a common constituent of many clays.

Amount of Soluble Salts.—The amount of soluble salts which may be permissible in a raw clay or shale without danger of efflorescence is not known. According to Ries[2] less than 0.1% is often sufficient to produce a white incrustation. Searle[3] says that as little as 0.01% of the sulfates of lime, magnesia, alkalies, ferrous iron and aluminum has been known to spoil facing brick. Dr. Mackler[4] is quoted as saying that "the amount of scum formed on finished goods bears no definite relation to the proportion of soluble salts contained; but there is quite a definite relation between the amount of the magnesium and sodium sulfates and that of scum." There are other factors involved concerning which we will speak further on.

Staley[5] has made an exceedingly interesting observation. He added calcium sulfate to a fine grained red burning shale in amounts increasing to 3% of the dry clay and was unable to produce efflorescence even with slow drying. When he added 1% of magnesium sulfate it appeared in large quantities and a 1% mixture of equal parts of the sulfates of calcium and magnesium gave an even greater amount of efflorescence. He explains this by pointing out that magnesium sulfate is very soluble in water while calcium sulfate has only a slight solubility. He also states that small amounts of calcium sulfate hastened the rate of drying which would act towards a decrease in efflorescence.

Barringer[6] experimented with a fireclay by adding increasing amounts of calcium sulfate and magnesium sulfate in the ratio of 3 to 1. Additions of these salts up to 3% did not show a corresponding increase in efflorescence.

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[1] Mellor, "Clay and Pottery Industries," p. 56.

[2] Ries, "Clays, Their Occurrence, Properties and Uses," p. 116.

[3] Searle, "Clayworkers' Handbook," p. 335.

[4] Mackler, *Ibid.*, p. 243.

[5] Staley, *Trans. Amer. Ceram. Soc.*, **17**, 200 (1915).

[6] Barringer, *Ibid.*, **4**, 224 (1902).

Determination of Soluble Salts.—Those interested in the procedure used in the determination of soluble salts are referred to the following literature:

Mellor, "Quantitative Inorganic Analysis," p. 630.
Mellor, "Clay and Pottery Industries," p. 53.
Grout, *West Va. Geol. Sur.*, III (1905), p. 26.
Ries, *New Jersey Geol. Sur.*, VI (1905), p. 76.
Ashley, *Bur. of Standards Tech. Paper* **23**, p. 96.
Bleininger, "Electrical Conductivity of Clays." *Trans. Amer. Ceram. Soc.*, **15**, p. 523.

Determination of Soluble Sulfates (Factory Method).—A factory method for the determination of the soluble sulfates which is simple in operation and requires very little apparatus is as follows:

Into each of several glass jars, the pint size fruit jar or a jelly tumbler will do, there are weighed equal quantities of the clay which have been dried previously at the temperature of boiling water. To these various jars equal quantities of distilled water are added and the samples are well stirred or agitated. If distilled water cannot be obtained, the water from condensed steam may be used or even rain water which has been gathered in clean receptacles after the first downfall has washed the air free from acid gases. In the vicinity of large towns or manufacturing plants, it is inadvisable to collect rain water for such a purpose. A dilute solution of a known strength of barium chloride is carefully prepared with distilled water. Into one of these several samples of clay is introduced a measured quantity of the barium chloride solution. To another sample is added a slightly larger quantity and so on gradually increasing the amounts of the barium chloride used. After stirring or agitating each sample thoroughly, they are allowed to stand for several hours in order that the clay may settle as much as possible. A small portion of the clear or slightly turbid water is carefully poured off from each jar. If turbid, it will be necessary to run these portions through filter paper and even boil them with the addition of a small amount of hydrochloric acid, or, as has been recommended, a solution of aluminum chloride. After a portion of the fluid has been removed from a sample and clarified, a drop or two of dilute sulfuric acid is added and the appearance of the fluid noted. If a white cloud forms upon the contact of the drop of acid, it is an indication of the presence of an excess of the barium chloride. Since the barium chloride which was added to the various portions has had an opportunity to react with the sulfates and to render them all or most of them insoluble, depending upon the quantity of the sulfates or sulfuric acid present, the presence of an excess of the barium chloride indicates that more than a sufficient amount of the barium chloride has been added to do the work for which it was intended, namely, to render the sulfuric acid and sulfates insoluble and therefore harmless. We will assume, by the way of an example, that the first five sample jars do not show any appearance of a white cloud or precipitate upon the addition of the drop of dilute sulfuric acid, but that the sixth jar does show this appearance. The sixth jar therefore contains an excess of the barium chloride. Since we know the weight of clay in the jar and the amount of barium chloride added to it, we are in possession of the necessary data for the calculation of the amount of barium chloride or barium carbonate which is required for addition to any known weight of the dry clay.[1]

Water as a Source of Soluble Salts.—It not infrequently happens that the water used in the manufacture of wares is the cause of the appearance of efflorescence. It should always be considered in the investigation of the cause. Very frequently information regarding the local supply may be had through some State Bureau, such as our own Water Survey.

If the water supply is contaminated by waste from factories, drainage from mines or town sewage, trouble may follow. Unfortunately, definite information regarding the relation between the condition of the water and the appearance of soluble salts is not available.

Prevention.—It has been stated that weathering for a limited period may cause or aggravate the trouble while long-continued thorough weathering will prevent the difficulty by dissolving and removing the salts. For a similar reason the elaborate process of washing clay, such as used by potters, affords an excellent means for removing soluble salts. This, however, is too expensive for brickmaking.

The method of prevention most commonly employed is the addition of some compound of barium to the clay. The principle which lies at the basis of this practice, is to convert the sulfates of lime and magnesia into less soluble salts. The relative solubilities[2] are as follows:

One part of	Parts of water
Calcium sulfate	495.0
Magnesium sulfate	3.75
Barium carbonate	45,450.00
Barium sulfate	435,000.00
Calcium carbonate	77,000.00
Magnesium carbonate	9,400.00

If we add barium carbonate to a solution of calcium sulfate we immediately initiate a chemical reaction which gives as final products barium sulfate and calcium carbonate. An inspection of the above table will show that both the calcium carbonate and the barium sulfate are far less soluble than the original salts. The same is true of the magnesium carbonate which will be formed in a like manner. Therefore, this procedure is a sound one in theory as well as in practice.

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[1] Detailed information regarding this test has been frequently printed, but will be gladly supplied by the author to any interested party.

[2] Staley, *Trans. Amer. Ceram. Soc.*, **17**, 201 (1915).

There are some variations which should be noted. One is the use of barium chloride for part of the barium carbonate. This is a very readily soluble salt which is of advantage since it may be more uniformly and intimately distributed throughout the clay mass whereas the slight solubility of the barium carbonate limits the speed of its action, and longer time is required for it to act effectively.

The very solubility of the barium chloride necessitates caution in its use because an excess over that actually required may be accompanied by the appearance of the barium chloride as an efflorescent salt. The best and usual practice is to add nearly the required amount of barium chloride and enough of the barium carbonate to take care of the last remnant of soluble salts. A reasonable excess of barium carbonate will be unobjectionable.

In recent years, the use of barium fluoride has been proposed as a desirable substitute for the barium carbonate and barium chloride. It is soluble in 614 parts of water and therefore is much more soluble than the carbonate and consequently it is more efficient. It is much less soluble than the chloride. Therefore, an excess will be less dangerous. According to Mr. Staley, who recommended it, it has no deleterious effect upon the color of the burned ware and it promotes vitrification.

Method of Introducing the Barium Salts.—The most rational and most efficient method is to provide a suitable tank with a stirrer in which the barium salts may be dissolved or suspended in water. Keep this mixture constantly agitated and feed regularly and uniformly into the clay mix.

Amount of Reagent.—The amount of barium carbonate to be added is commonly in large excess of the theoretical quantity. In fact, we find instructions in text-books to the effect that the amount should be ten times the calculated theoretical quantity. Undoubtedly an excess is ordinarily needed since the barium carbonate has such a low solubility that it must be generously distributed in the clay batch in order to be reasonably effective within the limited time for action. It is not good practice to use amounts in large excess, however, since thereby the costs are increased and further the color[1] of the brick may be lightened or impaired. One[2] experimenter has noted that in several trials he did not find it necessary to use an excess of the reagents.

Seger[3] directs that twice the theoretical quantity of barium carbonate be used.

[1] Staley, *Trans. Amer. Ceram. Soc.*, **17**, 202 (1915); Layman, *Ibid.*, **18**, 265 (1916).

[2] Staley, *Ibid.*, **17**, 202 (1915).

[3] Kerl, Cramer and Hecht, "Abriss Tonwaarenindustrie," p. 523 (1907).

Owing to the low solubility of the barium fluoride, an excess of it is not to be feared and as previously stated it does no harm to the color of the ware.

The Use of Common Salt and Carbonate of Soda.—The use of small amounts of common salt and soda ash (*i. e.*, sodium carbonate) has been proposed and interesting results have been reported.[1] Additions of these chemicals in amounts up to two per cent increased the amount of the efflorescence in the drying, but there was none on the burned ware. One clay which normally showed a heavy scum when burned, showed progressively decreasing amounts of the scum as the amount of these chemicals was increased. Mr. Staley, who has reported these results, is of the opinion that the heavy deposits of the common salt and the sodium carbonate which came to the surface during the drying served to volatilize or flux the normal scum. He says, further, that the effect of the sodium carbonate slightly darkened the color and the sodium chloride produced a brighter, clearer color. It is desirable that further investigation of the use of the salts and other chemicals should be made on a variety of shales and clays in order that we may know more about the possibilities of what appears to be a very promising procedure.

Drier White.—This is an efflorescence which appears during the drying period. The causes are:

(1) The use of the gases of burning kilns (scumming).
(2) The presence of soluble salts in the clay.
(3) The presence of soluble salts in the water used in the manufacture of the ware.

The harmful effect of the waste gases of burning kilns upon damp ware is so well understood that only a few words should suffice to emphasize the necessity for avoiding the practice. Such waste gases from burning coal, gas or oil will contain more or less of the oxides of sulfur. These gases (sulfur dioxide and sulfur trioxide) will combine with the water present on and in the ware and form strong acids which react very promptly with the carbonates of lime and magnesia and with any alkali salts which are present in a form which is readily attacked. The products of such reactions are the sulfates which form the efflorescence on the unburned ware. Therefore, this method of drying is suited only for wares which are not harmed by the formation of the efflorescence.

The character of the soluble salts which are in clays and in the water which is used has already been discussed. It is the movement of these soluble salts in the clay ware during the drying which is now our concern. The factors which influence the appearance of the efflorescence are:

(1) The degree of solubility of the compound present.
(2) The amount and the size of the particle of the soluble salt present.
(3) Temperature.

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[1] Staley, *Trans. Amer. Ceram. Soc.*, **17,** 702 (1915).

(4) Capillary structure of the piece.
(5) Rate of drying.
(6) Amount of water to be removed.

Solubility.—The more soluble the compound the more freely it is taken into solution and the greater the amount of efflorescence. Thus the formation of barium sulfate in the ware is not a source of trouble because one part requires approximately 435,000 parts of water to dissolve it. On the other hand, magnesium sulfate is extremely troublesome because one part dissolves in 3.75 parts of water.

Size of the Particle.—Gypsum, *i. e.*, the mineral calcium sulfate, if present, which is a frequent occurrence, will be found in lumps, grains, films and as minute crystals. The carbonate of lime may be present in lumps and grains of widely varying sizes. The carbonate of iron will be found in a great variety of sizes. The sulfates of iron, aluminum and magnesium are present probably as small crystals, films or stains. It is scarcely necessary to state that the size of the particle has a direct bearing upon the rate at which it will go into solution. Choosing a homely example of this, we know that granulated sugar dissolves more rapidly in a cup of tea than a lump of the same.

Temperature.—In general, chemical compounds dissolve more rapidly in hot water than in cold. Therefore as the clay wares are warmed in the course of the drying, a greater amount of the soluble compounds goes into solution.

Capillary Structure of the Ware.—All unburned clay wares and much of the burned are permeated with an extensive system of connected pores or tubes of extremely small diameters which we call capillaries. Through these capillaries the water in the ware makes its way to the surface during the drying process. The movement of the water in the capillaries is greatly retarded by irregularities in the walls and the tortuous path which they follow. Also, the rate of flow in the capillaries diminishes rapidly as the diameters of the capillaries decrease in size. Therefore, we find that the finest grain clays have the most extensive system but the smallest capillaries and accordingly dry the slowest. The slow rate of drying is most favorable for the solution of the salts. In so far as we can open up the structure of the wares, that is, create a system of large capillaries in place of the finer ones, to that extent we hasten the progress of the drying, reduce the time that the water can exert its solvent action and lessen the amount of efflorescence. An excellent example of this phase is the fact that dry press brick do not often show efflorescence. This is due in part to the fact that a minimum amount of water is used in the process of manufacture and also to the more porous structure of the ware during the drying and early stages of the firing.

Rate of Drying.—As previously stated the longer the water in the clay ware stands in contact with the soluble salts, the greater the amount that will go into solution, especially as the temperature increases. It naturally follows that the drying operation should be carried through as rapidly as is consistent with safety. If the drying operations are so imperfect as to subject the ware to an atmosphere so charged with humidity that moisture condenses on the colder brick, which sometimes happens, the moisture thus condensed may readily penetrate the surface of the ware and take into solution large quantities of the salts.

Use of Organic Coatings.—It has been proposed to coat the clay wares with glue, flour, starch or rubber before drying. This may act in a favorable manner in at least two ways. (1) The drying proceeds through the evaporation of water from the surface. If a surface is coated in such a manner as to retard or prevent the evaporation of the water from it, then the chief movement of the water will be to and from the uncoated surfaces. That is, the course of the movement of the water current carrying the soluble salts will be to the other surfaces where they may not be objectionable. (2) The soluble salts, *i. e.*, sulfates are decomposed during the burning operation and rendered unobjectionable. (3) The soluble salts may be carried into the surface coating and there deposited. Subsequently the coating dries and falls off. This may apply to the use of flour, starch and glue but not to the use of tar as has been proposed.

A Test for the Presence of the Salts on Dried Ware.—After the ware has been dried, scrape off a portion of the surface of the same and then burn the ware under such conditions as to prevent the formation of the kiln white. If the burned ware shows salts on the unscraped portion, but not on the scraped, it is obvious where the trouble originated.

Setting of the Brick on the Drier Cars.—The manner of placing the brick upon the drier cars must have an influence upon the movement of the water in the ware and consequently the place of deposition of the salts. That is to say, the faces of the brick which are exposed to the air dry freely while those in contact dry only by the removal of the water through the capillaries leading to the outer surfaces. Therefore, the efflorescence appears on the exposed surfaces only.

Kiln White.—According to the classification previously discussed we may consider the occurrence of surface coatings upon burned ware under two heads, namely, efflorescence and scum.

Efflorescence.—That is the deposition upon the surface of soluble salts which have originated in the interior of the ware and have been brought to the surface in solution. These may have been present originally in the raw clay and may have come to the surface during the drying process in the driers or during the early state of the firing.

Scum.—This is the surface coating of salts formed by the action of kiln gases during the early period of the burn. The chief and probably only offenders are the oxides of sulfur—sulfur dioxides and sulfur trioxide—which are evolved by the burning fuel and by the decomposition of the pyrites present in the clay. It is altogether likely that we have chlorides of sodium and other bases present in the fuel which react in some way with the clay wares, but it is doubtful that they have a harmful effect upon the ware. If present during any part of the burning period they are decomposed and react upon the clay wares without leaving any surface indications. As I will show further on, these chlorides may exert a different effect during the cooling period.

Sulfur in the Fuel.—All fuels contain variable amounts of sulfur occurring in different forms. Wood is practically free from it and the little which it contains has a negligible influence upon clay wares. Therefore, it has long been esteemed the most desirable fuel for use in burning decorated pottery, since the colors will then give the most desired effects. However, wood is no longer available in sufficient quantity and sufficiently cheap to be considered as an available fuel for most clay wares.

Peat, which is an abundant fuel in some parts of this and other countries, is also a desirable fuel for the same reason.

However, the fuels which are available in quantity and at a suitable price contain more rather than less sulfur and the problem is to use them intelligently in order to minimize the inherent bad qualities.

Sulfur is present in coal, oil and gas in a variety of forms. The most readily distinguished and most abundant in coal is the sulfide of iron. Sulfide of iron is one of the important raw materials used in the manufacture of sulfuric acid. The other essential raw materials are free oxygen and water. When fuel containing pyrites is burned in a furnace of any type we have the same materials and the same conditions as are obtained in the manufacture of sulfuric acid. If the temperature of the kiln is sufficiently high, this acid will pass through the kiln with little or no effect upon the ware. But during the early stages of the burn the story is quite different.

Brick set in a kiln are never entirely dry. Usually the drying process falls far short of being complete and a considerable amount of water is retained. Even when dried at 212° F the clay clings tenaciously to a small percentage of water. But assuming that the drying operations have been ideal, as soon as the dry ware cools below its drying temperature it promptly appropriates moisture from the atmosphere which may amount to 10% of its weight. This happens during the period of its transfer from drier to the kiln and during that period in the kiln when it is at a temperature of 212° F and lower.

Part of the moisture which the clay grabs is supplied by the air passing through the kiln and part by the water which is always one of the products of combustion.

The conditions which we have to consider during the early stage of the burn are therefore—a mass of moist cold brick, and a plentiful supply of the oxides of sulfur. The result is a condensation on the moist brick of dilute sulfuric acid which clings tenaciously to the clay and attacks vigorously the mineral material. The carbonates of soda, potash, lime, magnesia and iron speedily succumb and their sulfates are formed. Other minerals offer more resistance but the oxides of iron and evidently certain silicates of alumina and other bases yield in greater or less degree. An excellent example of the course of this action is observed with limey clays. These normally burn to a cream color. Under certain conditions we obtain ware flashed red. The red color is due to the action of the sulfur gases upon the lime, changing it to the sulfate and permitting the iron oxide present to exert its normal influence upon the development of a red color.

Water-Smoking.—The proper method of treatment of a kiln during the water-smoking period of the burn is to remove the moisture from the ware and to warm up the ware as speedily as it is safe to do so. This may be accomplished by stimulating the flow of a large volume of heated air through the kiln, which may be difficult to accomplish owing to the sluggish draft of cold flues and stack. If so, a fan may be used advantageously or the kiln may be connected with a stack which is serving a kiln already under high fire, or a small fire may be built at the base of the stack.

Further it is of advantage to water-smoke with fuel having a low sulfur content such as wood, anthracite coal or coke. All of these fuels are used in various parts of the country during the water-smoking period with good effect.

Setting of the Ware.—The manner in which ware is set has much influence upon the progress and amount of scumming and efflorescence. Ware set too closely in a kiln retards the draft and thereby facilitates scumming. A friend recently showed me an example of brown scumming which developed on brick set in an open kiln. It has been suggested as an explanation for this case that the courses were set too closely, especially at the top and therefore the acid gases attacked available iron and alumina compounds forming soluble salts which left a yellowish brown discoloration. A similar occurrence is reported to have been observed on buff brick burning in the ordinary kilns with crowns.

As already explained, the portions of bricks which are in contact with each other do not show the salts, but only the exterior surfaces exposed to the kiln gases.

Oxidation and Reduction.—The oxidation of the pyrites to form sulfuric acid takes place only in the presence of an ample supply of free oxygen. The sulfates of lime, magnesia and the alkalies form therefore only under oxidizing conditions. It naturally follows that reducing condition, *i. e.*, burning with an insufficient supply of oxygen is unfavorable for the formation of sulfates. Consequently, we have the use of reducing condition as a method of preventing the development of sulfates. Also by reduction it is possible to convert the sulfates already formed into sulfites which decompose readily under the influence of heat.

Influence of Hard Burning.—The amount of soluble salts formed on burned ware does not seem to be closely related to the amount of soluble salts in the clay. However, the amount of soluble salts in ware decreases as we burn the ware at higher temperatures, for example:

A soft burned brick contained 0.4 to 0.5 per cent soluble salts. The same brick burned harder contained only 0.001–0.003 per cent soluble salts.

Ries[1] cites an example of a limey Wisconsin clay which contained a few tenths of a per cent soluble material. When burned at different temperatures it gave the following results:

A—softest burn.........	4.50% sol. salts
B	2.20% sol. salts
C	1.42
D	1.23
E—hardest burn........	1.03% sol. salts

However, as shown in the above table only part of the soluble salts becomes fixed. Another investigator[2] found that only a little more than a third of the total soluble salts were fixed by burning of a fire brick.

Experiments of A. E. Williams[3]—Laboratory experiments on the effect of volatilizing ferric chloride in the kiln during the burning gave good red colors free from scumming. Factory experiments on the application of a solution of two pounds per gallon per three thousand bricks was promising of good results although not quite satisfactory. Similar experiments using a solution of the sulfate of iron and applying it to the damp brick prevented scumming, but was not as effective as the ferric chloride.

Alkaline Scum.—According to Searle's *Clayworkers' Handbook*[4] this may be due to the use of oil containing soap. It appears as patches of glazed surface on the ware.

Temporary Scum.—A form of soluble salts which apparently has not been discussed in literature, although seemingly frequently observed, is the appearance of a whitish coating upon brick in the kiln after opening the same, especially upon those near the door; or appearing upon the brick soon after removal from the kiln. Its appearance seems to be influenced by general atmospheric conditions. Further, this white coating is readily removed by washing the brick and once removed is permanently gone.

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[1] Ries, *Rept. Wis. Geol. Surv.*, p. 21.

[2] *Trans. Amer. Ceram. Soc.*, **18,** 611 (1916).

[3] *Ibid.*, **17,** 764 (1915).

[4] P. 335.

The recent microchemical examination in our laboratory of some bricks with such a coating showed that the deposit was chiefly sodium sulfate with sodium chloride (common salt), a little calcium sulfate and no magnesium sulfate. This result is surprising and very interesting.

My inference from this analysis is that these salts were deposited during the cooling of the kiln and that they do not originate in the ware.

My reasons are as follows:

If they had been present in the ware, the sodium chloride particularly would have been volatilized and dissipated in the kiln gases or decomposed and the sodium would have attacked the clay and become permanently fixed. Just as for example in salt glazing, the salt thrown into the kiln is converted into a gas and is decomposed by the hot ware forming a glaze. The sodium sulfate either was volatilized and deposited on the ware, or more probably salt vapor was present and was attacked and changed to sodium sulfate. The ware does not show a glaze because the amount of these salts is small and because they are deposited at a *temperature too low to form* a glaze.

The source of the sodium which has formed the chloride and the sulfate is probably the fuel left on the grates during the cooling, or the ashes and clinker. For example, we know that certain coals contain notable quantities of sodium chloride, so much so that the effect of it upon refractories in coking furnaces is being carefully studied in England.

The sulfur oxides which have combined with the sodium to form the sulfate have come from the burning fuel left on the grates and from the clinker.

These salts are both readily soluble in water and may be easily and permanently removed by washing the brick.

To prevent their occurrence, if I am correct in my theory of their formation, the fire boxes and ash pits should be cleaned of their contents when the firing is completed, and before cooling.

I offer the above opinion as tentative and subject to modification, realizing that we still have much to learn about this peculiar occurrence.

Wall White.—The occurrence of a coating of white soluble salts upon brick set in the wall is known as "wall white," "wall saltpetre" or "wall nitre." Other discolorations, yellow, green, brown, etc., sometimes are observed. These may be due to the presence of vanadium salts,[1] vegetable growths, etc., which we will not discuss. The causes which bring about the formation of the soluble salts in the crude clay in the drying and the burning operations have already been mentioned. Bricks which normally are free from soluble salts, sometimes show them after standing in stock piles, or when built into the wall. The salts will be observed if the stock piles are built upon ground covered with cinders, ashes or slag.

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[1] Seger's "Collected Writings," p. 381 (Trans. by Amer. Ceram. Soc.).

The appearance of soluble salts upon brick built into the wall may be expected if soluble salts are present in the mortar or if lime is used too freely in the mortar batch. Professor Kloes in his interesting book, "A Manual for Masons"[1] says that the "addition of lime to Portland cement is about the worst thing that can be done," and he cites numerous instances of the bad results following such a practice. He advocates the addition of some hydraulic agent such as kieselguhr (*i. e.*, infusorial earth), powdered brick, slag, etc., to the lime-cement mortar to prevent the leaching out of the soluble salts.

Notwithstanding Professor Kloes' opinion, the addition of lime to Portland cement mortar is a very common practice because it renders the mortar more easily workable under the trowel, is supposed to act as a waterproofing agent in the mortar and to some degree lessens the cost of the mortar. Numerous instances of the pernicious effects of its excessive or improper use with brick, glazed brick and architectural terra cotta may be cited, however, in substantiation of his views.

The addition of gypsum or plaster of paris to Portland cement mortar makes it more plastic and easier to set, but it is altogether probable that it will find its way eventually to the surface of the brick and appear as wall white. Therefore, its presence in or addition to mortar is highly objectionable.

Of course, soft burned porous brick are much more likely to develop "wall white" than the hard burned brick of low porosity. The porous brick are easily wetted by rains and the water thus absorbed gradually dissolves and brings to the surface fresh additions of salts.

Care in waterproofing certain parts of the masonry such as foundations, parapet walls and cornices should be observed. Manufacturers of architectural terra cotta have learned from experience the great importance of care in preventing the access of water to the body of their wares when built into structures.

Soluble salts on masonry may arise, also, from the "kind" of sand used in the mortar, from their presence in the mortar, colors which are used, from the addition of salt to water used in mixing mortar in very cold weather.

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[1] Translation by A. B. Searle, p. 148.

NEED FOR MORE REFRACTORY HEAT INSULATORS

Proposed Conductometers for Measuring Thermal Conductivity[1]

By Robt. D. Pike

ABSTRACT

The commercial value of high temperature thermal insulators is discussed, and a numerical example of a problem in designing a flue for conducting hot gases is given. A suggestion is offered for carrying out research in the manufacture of more highly refractory thermal insulators than are at present available, and tentative specifications for refractory and insulating properties are given. It is further suggested that refractory manufacturers should interest themselves in such research. The need of a simple apparatus, called for convenience a conductometer, for carrying out routine investigations of thermal conductivity, is pointed out, and, after describing some of the more important apparatus formerly used, a design of an improved new type is suggested and the method of working up the results is described.

Introduction

One of the pressing needs of the combustion engineer is an enforceable specification covering both the refractory and heat insulating properties of refractory and insulating materials. This will call for a greater combination of refractoriness and insulation than is at present attainable. So far as known to the writer, the optimum combination of these two properties is now found in a brick made from calcined diatomaceous earth. The makers claim that this brick may be safely used up to 2300°F and that the conductivity in English units (K) varies from 1 to 3. Several insulating bricks are obtainable which can be safely used up to 1600–1700°F and which have a conductivity (K) of 1 to 1.5.

There appears to have been no consistent attempt to place on the market insulating bricks which could safely be used at temperatures in excess of 2300°F and which would possess considerable value as heat insulators. There is no theoretical reason why such bricks could not be manufactured, and furthermore there is no doubt of their great prospective value in many cases.

To illustrate one aspect of this value the writer has worked out a numerical example of insulating a flue, in which a hypothetical high temperature insulator is employed. This example is an extreme case, and has been so chosen to clearly bring out the point.

Example Showing Need of Refractory Insulation

The structure considered is a vertical flue of inside dimensions 18″ x 18″. This flue carries clean gases of combustion at a temperature of 2800°F at a velocity of 16 feet per second. It is proposed to construct this flue out of refractory and insulating materials. Suppose the designer had at his disposal only the following:

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[1] Refractories Division, St. Louis Meeting, Feb., 1922.

Fire brick with conductivity (K) = 9.
Non-refractory insulating brick good to 1600°F with $K = 1$
Common brick.

The flue would then be constructed somewhat as in Fig. 1. The heat loss due to radiation and convection to the outside atmosphere for every foot of the flue is about 4750 B. t. u. per hour; the temperature of the inside face of the insulating brick is 1650°F and the weight per linear foot is about 2440 pounds.

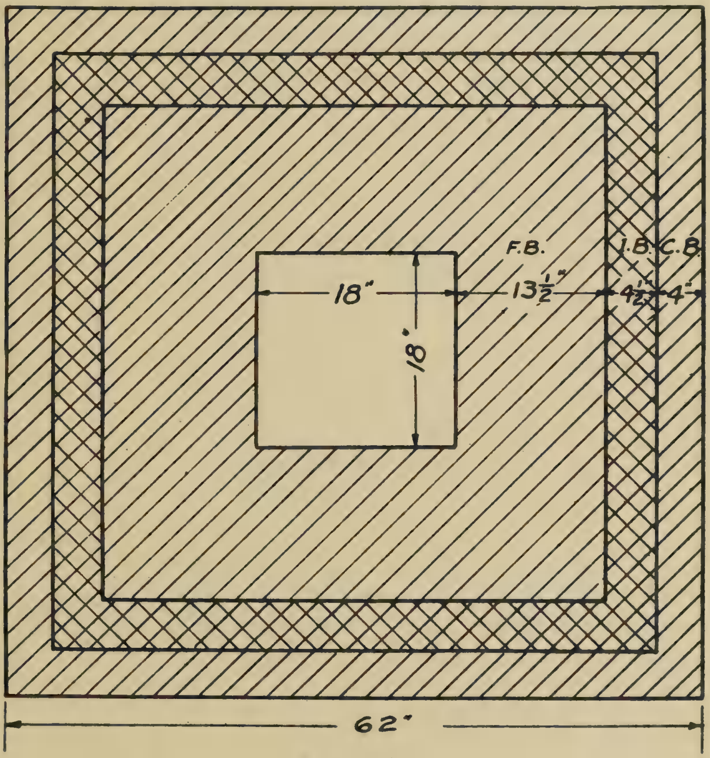

FIG. 1.

LINING 13½" F.B.
4½" I.B. (NON-REFRACTORY)
4" C.B.

But suppose in addition to the materials listed above the designer had at his disposal the following refractory insulating bricks (high temperature insulator). Refractory insulating brick good for exposure to clean gas at 2800°F and having $K = 2$ and possessing the necessary structural strength for the intended service.

Under these circumstances the flue could be built as shown in Fig. 2. The loss per linear foot would be 2900 B. t. u. per hour; the temperature of the inside face of the non-refractory insulating brick would be about 1640°F and the weight per linear foot would be about 866 pounds.

The flue shown in Fig. 2 would weigh only 35.5% of that shown in Fig. 1, and the heat loss would only be 61.0% as great.

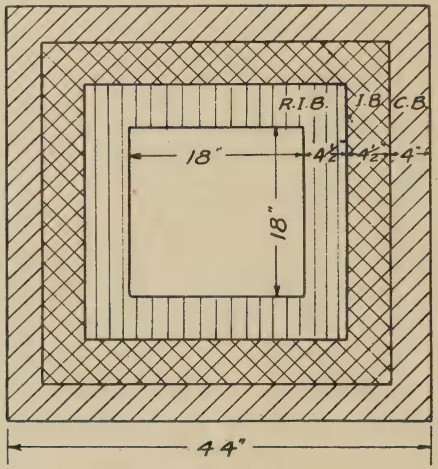

FIG. 2.
LINING 4½" REFRACTORY
INSULATING MATERIAL R.I.B.
4½" INSULATING BRICK (I.B.) (NON-REFRACTORY)
4" C.B.

In the foregoing example Langmuir's[1] data has been used for estimating the thermal resistance of the surface film of gas inside the flue and the loss of heat by radiation and convection from the outside surface; and Langmuir's[2] formula has been used for calculating the shape factor.

Relation between Flare of Walls and Insulating Requirements

As already pointed out, this example represents an extreme case, and this is principally so because of the sharp flare of the walls of the flue, and to the highly favorable nature of the hypothetical high temperature insulator. But all furnace walls have more or less flare, and on this account alone the closer the heat insulator can be placed to the inside surface, the lighter in weight will be the structure and the better the insulation; and furthermore even when the flow of heat through a wall may be considered to take place in parallel flow lines without serious error, *i. e.*, when there is little or no flare, it is obvious that the more refractory the heat insulator, the closer it can be placed to the inside surface of the furnace, and the thinner can be the refractory lining, and the lighter the weight of the entire structure.

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[1] "The Convection and Radiation of Heat," by Irving Langmuir, *Trans. Am. Elec. Chem. Soc.*, **1913.**

[2] "Flow of Heat through Furnace Walls;" "The Shape Factor," by Irving Langmuir, E. Q. Adams and C. S. Meikle, *Trans. Am. Elec. Chem. Soc.*, **1913.**

Where Insulation Is Sacrificed for Want of Refractoriness

An important conclusion arising from consideration of the flare of furnace walls is that insulating property can be sacrificed to some extent if there is a corresponding gain in refractory property while maintaining equal insulation effect, and this fact opens up the possibility of a new type of brick which would find application in a large number of structures, *i. e.*, in all furnaces, flues, etc., where the flare of the walls is a factor.

Research and experience alone will finally show just what combinations of refractory and insulating properties may be attained in practice, but the following table may be considered as a tentative suggestion, covering the entire range from non-refractory insulating to refractory non-insulating materials.

TABLE I

TENTATIVE RANGE OF REFRACTORY AND INSULATING PROPERTIES OF MATERIALS FOR FURNACE CONSTRUCTION

Type	Approximate upper limit of working temperature when exposed to clean non-corrosive gases	Conductivity *K* Eng. units at average working temperature	Present state of art
1. Refractory, non-insulating	2700 °F–3000 °F	8–10	Represented by commercial refractory bricks.
2. Semi-insulating refractory	2600 °F–2800 °F	3.0–5.0	Hypothetical material.
3. Refractory insulator. High temperature insulator	2500 °F–2800 °F	1.5–3.0	Hypothetical material.
4. Insulating, semi-refractory	2300 °F	1–3	Bricks made from calcined diatomaceous earth.
5. Insulating non-refractory	1600 °F	1–1.5	Bricks made from diatomaceous earth and like substances.

Consideration of placing insulation back of refractories, involves the ability of the refractory to withstand the more severe heat conditions. Thus far the refractory manufacturer, and the maker of insulating materials have followed more or less independent paths; without evincing that reciprocal interest in each other, which is needed to place at the disposal of the furnace designer, the materials for most efficient design, all factors being considered.

Need of Refractories Having Insulating Properties

The writer ventures to urge that refractory manufacturers begin to give attention to the heat insulating aspect of refractory bricks in addition to the other properties now embodied in standard specifications. In short, a question of this sort should be answerable; given certain conditions of temperature, gas velocity, dust conditions, etc., on the inside of a wall, how much insulation may be safely applied on the outside? Or, putting the matter in another way, What is the smallest temperature gradient through the refractory compatible with safety and long life? And beyond this, the further suggestion is urged that refractory manufacturers undertake research in the manufacture of high temperature refractories occupying the upper region of the foregoing tentative table. Such research can be followed along the lines of experimenting with various sizes and numbers of pore spaces in a given volume, combined with various refractory bodies.

The successful manufacturing of insulating materials demands an apparatus capable of commercial application for determining with a fair degree of accuracy the conductivity at different temperatures. The writer would not go so far as to say that such an apparatus is not available, but certainly it would seem that none such has been adopted. Possibly this is because of the complexity of the various types of apparatus described in the literature, and the very evident lack of any uniformity in method among experimenters. Thus far the measurement of thermal conductivity appears to have been most largely laboratory research rather than routine commercial testing or control of a commercial process.

Methods of Measuring Heat Conductivity

Clement and Egy[1] measure the current input into an electrical resistance placed along the axis of a special hollow cylindrical test piece; and determine the temperature at two points in the wall. The necessity for using a special test piece rules out such a method for practical routine work.

Griffiths[2] reviews the work of other investigators and points out the requirements for the accurate use of the flow calorimeter. Readings were made at several temperatures and several days were required to complete a test on one specimen, because a new steady state had to be reached for each temperature.

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[1] "The Thermal Conductivity of Fire Clay at High Temperatures," by J. K. Clement and W. L. Egy, *Univ. of Ill. Bull.*, **6**, No. 42, Aug. 2, 1909.

[2] "The Thermal Conductivity of Materials Employed in Furnace Construction," by Ezer Griffiths, *Trans. Faraday Soc.*, **12**, 193–206 (1919).

Dougill, Hedsman and Cobb[1] used a flow calorimeter.

The temperature of the hot face of the test brick was maintained by a gas burner and thermocouples were placed in the hot and cold face of the test piece. This method suffers from the same disadvantage as the preceding one of Griffiths, in that a separate steady state of temperature must be attained in the test piece for the determination of conductivity corresponding to each different mean temperature between the faces.

Dudley[2] constructed a coke-fired furnace, one wall of which held the test brick. A flow calorimeter with guard ring was used and temperature readings were made every quarter inch from the hot to the cold face. By this means Dudley was able to calculate the temperature coefficient of conductivity from a single set of readings which enabled him to complete one test a day. The thermocouples were inserted into the brick perpendicular to the isothermal planes, whereas for accurate work the couple wires should parallel the isothermal planes. In addition to this criticism the apparatus is rather cumbersome.

Randolph[3] used a flow calorimeter with guard ring, and an electrically heated hot plate. There are no new features as compared with Griffiths.

Heyn, Bauer and Wetzel,[4] used an entirely different method, inasmuch as a steady state was not reached and time was considered as one of the variables. The test piece was heated quickly from a hot face and the cold end acted in effect as a calorimeter. The conductivity was calculated from the time temperature curve of two couples, one at the hot face and the other 1 to 2 cm. distant, combined with a determination of the specific heat of the specimen. No calorimeter was required nor was it necessary to reach a steady state, but in spite of this simplification it is doubtful if the method is of value owing to the involved method of calculation, particularly in view of the fact that the results obtained are not closely comparable to those obtained from the flow calorimeter method.

Goerens and Gilles[5] placed the test brick over an electric hot plate. Several thermocouples were inserted in holes drilled to the center of the test piece and parallel to the isothermal planes. The test piece was surrounded by heavy insulation to insure parallel flow of heat from the hot face to the flow calorimeter, the central part of which occupied about one-third the area of the cold face, the balance of the cold face being covered by the guard ring of the calorimeter. This apparatus appears to be theoretically correct and practical in construction and is the closest approach to a practical apparatus for commercial work that is described in the literature. In fact, it is quite possible that an apparatus of this type could be adapted to routine work.

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[1] "The Thermal Conductivity of Refractory Materials," by G. Dougill, H. J. Hedsman and J. W. Cobb, *J. Soc. Chem. Ind.*, **34,** 465–71 (1915).

[2] "The Thermal Conductivity of Refractories," by Boyd Dudley, Jr., *Trans. Am. Elec. Chem. Soc.*, **1915**.

[3] "The Thermal Resistivity of Insulating Materials," by C. P. Randolph, *Trans. Am. Elec. Chem. Soc.*, **1912**.

[4] "Untersuchungen über die Wärmeleitfährigkeit feuerfester Baustoffe," Mitteilungen ausdem Königlichen Materialprüfungsamt, **32,** 89 (1914).

[5] "Über die Wärmeleitfährigkeit feuerfester Steine," by Von P. Goerens and J. W. Gilles, *Ferrum*, October, **1914.**

The proposed new instrument for measuring the thermal conductivity of standard nine-inch bricks of refractory and insulating materials is shown in Figs. 3 and 4. The principle of operation is to measure the temperature drop at one instant at several points along a bundle of heat flow lines of extremely small cross sectional area. This method is distinct from that used in a similar type of apparatus when a flow calorimeter is used to measure the heat flow. In this latter case the actual flow of heat passing a relatively large cross-sectional area of the test piece is measured during an appreciable time interval.

Proposed Commercial Control Apparatus

The proposed apparatus is in many respects similar to that of Goerens and Gilles,[1] but the flow calorimeter is supplanted by a disc-like member (*A*, in the Figures), having thermocouples embedded in its upper and lower faces and possessing a known thermal resistance. (It is presumed that this known thermal resistance will have been established once for all by the flow calorimeter method.) In short, any given difference in temperature of the two couples embedded in the disc shows immediately the rate of heat flow per unit area at the center of the disc, when such flow is perpendicular to the respective faces.

Referring further to Figs. 3 and 4, *b* is a centrally located surface combustion burner in a carborundum pot designed to hold the test brick on its end or on its side (the latter disposition would be used when the test piece was composed of highly insulating material). *c*, is a "guard ring" burner, which sets up a heat flux in the material, *d*, which has substantially the same conductivity as the test piece, *e*. *f* is an insulating covering. *g* is a transite board standard, drilled to hold the thermocouples in accurate alignment. The test piece is drilled with 3 (or 6) holes to center, through a template corresponding to the holes in the transite standard. It is then inserted in the central hole over the burner, *b*, and the thermocouples pressed home and secured. A smooth upper surface is then secured with a suitable cement and the standard resistance, *a*, is pressed into place. The resistance of this latter is so chosen that for the given test piece, when

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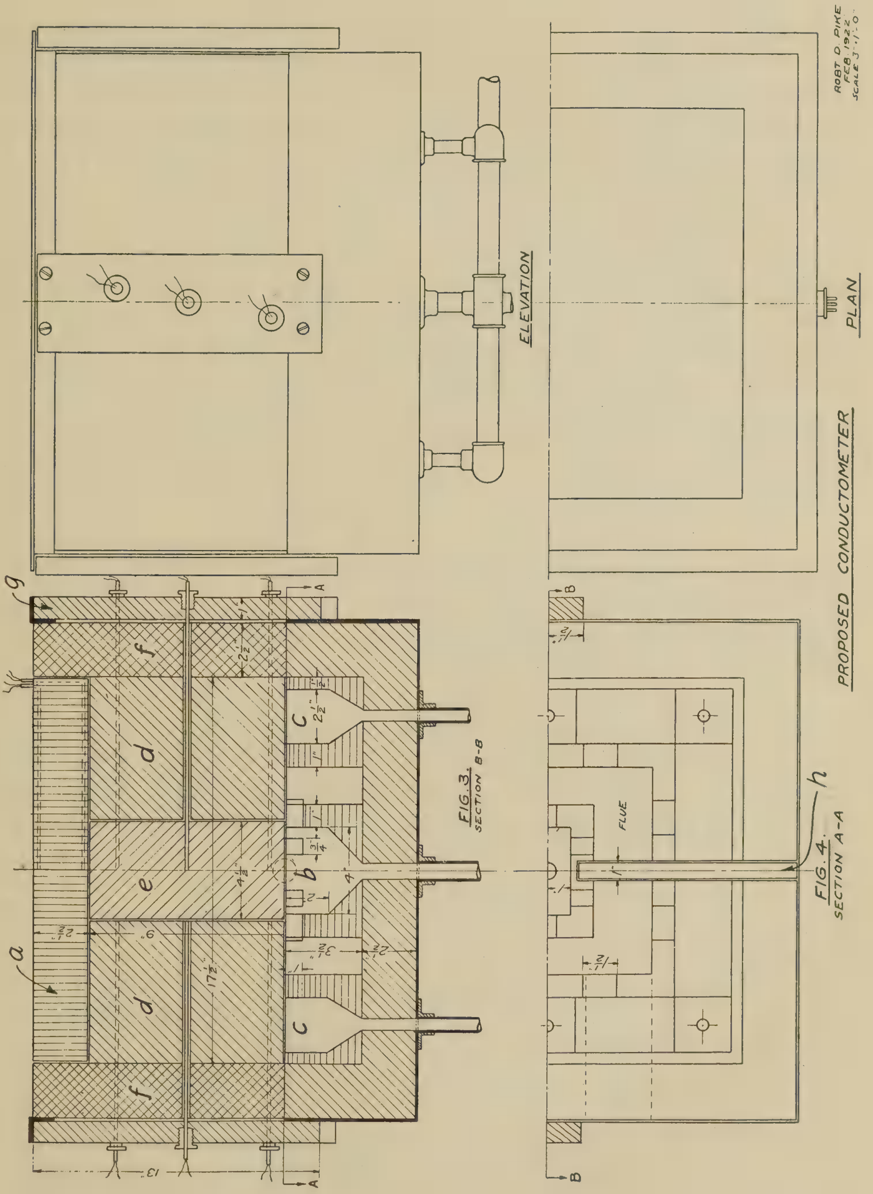
[1] *Vide supra.*



PROPOSED CONDUCTOMETER

FIG. 3. SECTION B-B

FIG. 4. SECTION A-A

the hot face is at its maximum steady temperature, about two-thirds of the total temperature drop will be across the test piece and one-third across the standard disc.

The burners are turned on and when a steady state has been reached, as indicated by observations with an optical pyrometer, through the carborundum tube, *h*, and by the attainment of a flat time temperature curve with the thermocouple nearest to the cold end of the test brick, a simultaneous set of readings is then taken on all the thermocouples, *i. e.*, on the 3 (or 6) embedded in the test piece, and the two embedded in the standard disc. This gives the data necessary for calculating the conductivity of the test piece expressed as a straight line function of the temperature.

The thermocouples which are embedded in the guard ring refractory are to insure that the temperature gradient through this near the test piece is substantially the same as the temperature gradient through the test piece, which condition insures parallel flow of heat along the central axis of the latter and along the central axis of the standard disc.

It should be possible to examine at least two specimens daily with such apparatus.

The mathematical basis of the calculation is given in the following:

Mathematical Considerations

Conductivity (K) is a straight line function of temperature, T, in accordance with the following equation:

$$K=a+bT \tag{1}$$

in which a and b are constants characteristic of the substance.

If one will write the differential equation for the parallel flow of heat between two infinitely close isothermal planes, substituting therein the value of K from Equation 1 and then obtaining the definite integral, the following equation results, which defines the temperature gradient

$$a(T-T_1)+\frac{b}{2}(T^2-T_1^2)+Wx=o \tag{2}$$

In which

a and b are the constants of Equation 1

T_1 is the temperature in °F on any hotter isothermal plane.

T is the temperature in °F on any cooler isothermal plane distant X inches from the hotter plane.

W is the flow of heat from the hotter to the cooler plane in B. t. u. per square feet per hour.

Returning now to the set of instantaneous readings from the proposed conductometer the temperature of the inner and outer faces of the standard disc immediately show the rate of heat flow per square foot per hour at the center of the disc and test piece from the known calibration of the former. This gives W of Equation 2.

Next, there are at least three temperature readings at measured points along the axis of the test piece. Call these points 1, 2, 3, reading from the hotter to the colder end. Equation 2 is now written substituting therein the value of T_1 for point 1 and T for point 2; and is again written this time calling the temperature at point 2, T_1 and at point 3, T; X is of course known in each case, because it is merely the distance between the thermocouples. This gives two equations from which the values of a and b can be solved, and substituting these values in Equation 1 gives the desired result.

If six readings are made in the test piece, these are divided into 2 sets of 3 each, and the same procedure is followed giving two independent sets of values for a and b. Theoretically these two sets of values should be identical, but actually there would always be some difference between them because of experimental error and the averages of the two sets should be used as the final result.

Dudley[1] in calculating his results uses a method which is essentially the same as the one described except that he first determined the shape of the temperature gradient curve and having found this calculated that the conductivity-temperature curve is a straight line. The writer uses this latter fact as the basis for his calculation.

It will be desirable in the interest of accurate determination of a and b to have the temperature of the hot face of the test piece at as high a point as permissible, considering the nature of the material, and it would seem that the use of the surface combustion principle would render this possible in all cases.

The hot face temperature can be attained if desired by any sort of an electric resistance.

It will be noted that the apparatus divides at the top of the carborundum pots, and the test piece and guard ring and insulation can be removed as a whole.

The writer has hesitated somewhat in presenting this paper because of the purely tentative and suggestive nature of the subject matter; but consideration of the urgent needs for development along the line of insulating all sorts of metallurgical furnaces finally brought the decision that its presentation would prove worth while if it only should result in some fresh discussion of the subject; or should give other workers in the same field some small suggestion for future improvement.

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[1] *Vide supra.*

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ORIGINAL PAPERS

THE PRODUCTS OF THE CALCINATION OF FLINT AND CHALCEDONY[1]

By Edward W. Washburn and Louis Navias

ABSTRACT

Outline of the Investigation.—This investigation includes the measurement of the following physical properties; specific gravity at 0°, 25° and 98°, the index of refraction, the coefficients of thermal expansion up to 300°, the inversion temperature and volume change on inversion, and the X-ray spectra, the materials studied being quartz, tridymite, cristobalite, silica glass and raw and calcined flint and chalcedony.

New Methods.—For specific gravity, a special vacuum pycnometer was employed and the immersed powder was later subjected to a pressure of 1000 atmospheres.

Results.—The numerical data obtained are summarized in Table I and the X-ray spectra are shown in Fig. 10. The specific gravity of calcined chalcedony was raised 2% by fine grinding.

Conclusions.—All of the known facts concerning chalcedony are in harmony with the theory that the raw material is colloidal quartz and the calcined material colloidal cristobalite.

I. Introduction

1. Purpose of the Investigation.—Silica is known to occur in three distinct enantiotropic forms, each form having two or more enantiotropic sub-forms. These forms are quartz (α and β), tridymite (α, β_1 and β_2) and cristobalite (α and β) to which may be added silica glass, the amorphous or liquid form. The various transition and fusion temperatures

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[1] Received June 7, 1922. Presented at the St. Louis Meeting of the Society, March, 1922.

and the ranges of stable existence of all of these forms have been accurately determined by Fenner.[1] The position of the mineral chalcedony in this system has, however, never been satisfactorily established although Fenner seemed inclined to view it as a form different from any of the preceding.

The present investigation was undertaken as a contribution to the elucidation of the chalcedony puzzle and for the purpose of clearing up certain conflicting data and conclusions reported in the literature concerning the properties and nature of the products obtained through the calcination of flint and chalcedony.

Mineralogical Nature of the Materials

2. Chalcedony.—Chalcedony is a natural form of silica, described by the mineralogists as cryptocrystalline, occurring in translucent or opaque botryoidal, reniform, or stalactite masses composed of optically biaxial fibers. It is waxy or greasy in lustre, somewhat splintery in fracture and usually exhibits a banded structure.

3. Flint.—Flint is classed by the mineralogists as a type of chalcedony consisting largely of the siliceous remains of sponges, diatoms, and other marine organisms. It is thus sedimentary in origin and is not as pure as chalcedony proper. It is translucent to gray, brown, or nearly black, the coloring matter frequently being entirely organic in nature so that a black flint may become perfectly white on calcination. The term flint as used by the mineralogists and as employed in this paper is to be carefully distinguished from "potters flint," a commercial term employed in America to designate pulverized quartz.

The Work of Previous Investigators

4. The Work of Le Chatelier.—Beginning in 1889 Le Chatelier made a number of investigations of the different forms of silica and of their behavior on heating to high temperatures. A summary[2] of all of his previous work was published in 1913 and his main conclusions are as follows:

1. On heating, the expansion of chalcedony is similar to that of quartz and it shows a similar anomalous volume increase at 600°.

2. On heating to 1400° in a "porcelain kiln" chalcedony is transformed into cristobalite.

His expansion curves are reproduced herewith (Fig. 1).

The curve marked "cristobalite" in Fig. 1 is, in fact, identical with a curve marked "calcined chalcedony" in a similar diagram published in 1890 and has apparently been taken from the 1890 paper and relabeled.

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[1] Fenner, *Amer. Jour. Sci.*, **36**, 380 (1913); cf. Ferguson and Merwin, *Ibid.*, **46**, 417 (1917).

[2] Le Chatelier, "Revue Universelle des Mines," **1**, 85–142 (1913); also, "La Silice et les Silicates," Hermann et Fils, Paris (1914).

With reference to the specific gravity of the calcined chalcedony Le Chatelier states in his 1890 paper that the chalcedony was calcined at 1500° ("four à porcelaine dure") and had a specific gravity of 2.16, while in his 1913 paper he states that chalcedony calcined at 1400° has a specific gravity of 2.3. No explanation of this discrepancy is offered by Le Chatelier.

3. On heating quartz, or better still, chalcedony, to a high temperature, insufficient to produce tridymite, a form of silica, "Silica X," is produced which shows a sudden expansion at 210°.

Le Chatelier then gives his expansion data on this "X" form of silica and these data are identical with those expressed by his curve labeled "cristobalite" in Fig. 1.

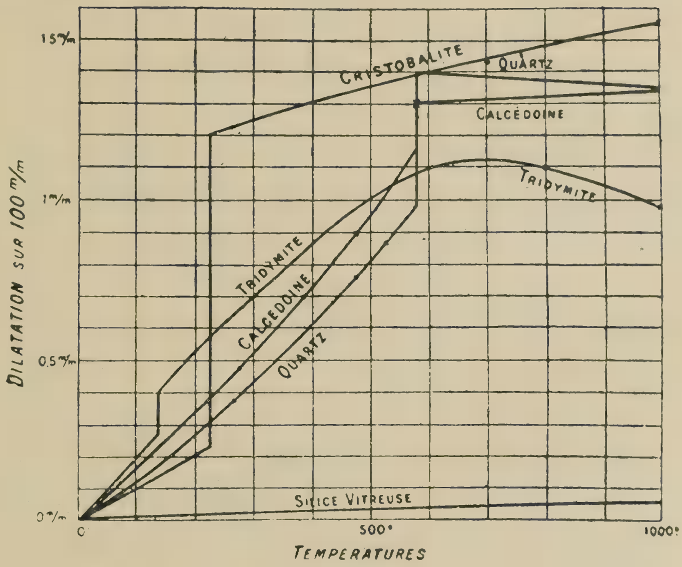

Fig. 1.—The thermal expansions of the various forms of silica. After Le Chatelier.

With regard to the behavior of raw chalcedony, Fenner,[1] who replotted Le Chatelier's results, concluded that they gave no satisfactory evidence of any transformation in the neighborhood of 600° and that is also our own conclusion based upon a study of Le Chatelier's data. Fenner also found by a thermal analysis of raw chalcedony that its cooling curve exhibited no thermal effect at the quartz α-β inversion temperature. In other words none of the above data indicated that raw chalcedony could properly be classified as a form of quartz.

Le Chatelier's determinations of the coefficient of expansion seem to indicate that the chalcedony which he studied transformed into cristobalite on calcination. His statements regarding its specific gravity are, however, conflicting. The value 2.3 is the specific gravity of cristobalite, while the value 2.16 agrees with the results for calcined chalcedony obtained by later investigators and is lower than the specific gravity of any of the recognized forms of silica.

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[1] Fenner, *op. cit.*, p. 380.

5. The Experiments of Rieke and Endell.—In 1913, Rieke and Endell[1] published an extensive investigation of the properties of various forms of silica after calcination. Their values for the volume changes produced by calcination are reproduced herewith (Fig. 2). They conclude that in the case of flint and chalcedony the product of calcination is cristobalite, a conclusion which is, however, not borne out by their specific gravity data as shown in Fig. 2. Their conclusion was based upon the dilatometric behavior of the calcined materials and their results will be referred to below in connection with our own.

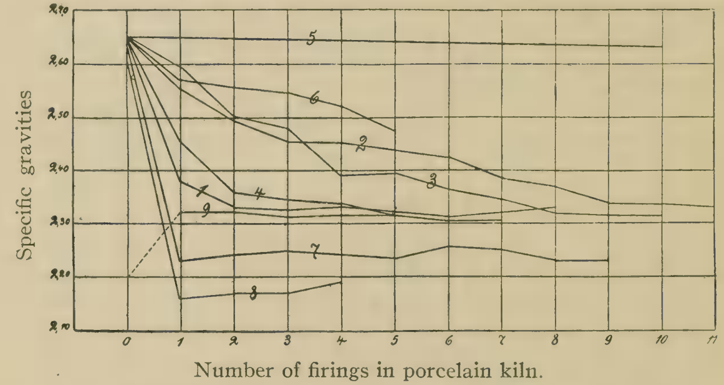

FIG. 2.—Effect of repeated calcinations upon the specific gravity of various forms of silica. After Rieke and Endell.

1. Norwegian quartz, in pieces. 2. Sand from Hohenbocka. 3. Gyserite from the Taunus district, in pieces. 4. Same pulverized. 5. Rock crystal, in pieces. 6. Same pulverized. 7. Flint, in pieces. 8. Chalcedony, in pieces. 9. Silicic acid.

6. The Experiments of Mellor and Campbell.—These investigators compared the volume changes which occur in calcining quartz and flint and called attention to the remarkably low specific gravity of the calcined flint. Their results[2] are reproduced in Fig. 3. These investigators likewise offer no explanation for the low specific gravity of the calcined flint.

7. Braesco's Experiments.—During the progress of the present investigation there appeared a paper by Braesco[3] giving some new data on linear expansion. The materials examined were cristobalite and

[1] Rieke and Endell, *Silikat-Zt.*, **1,** 52 (1913).

[2] Mellor and Campbell, *Trans. Eng. Ceram. Soc.*, **15,** 77–116 (1915–16).

[3] Braesco, *Ann. Physique,* **14,** 5 (1920).

tridymite. The powdered materials were formed into rods 5 cm. long by 8 mm. square, held together with 5 per cent of a 36 per cent solution of sodium silicate. These rods were heated in a tube furnace together with a rod of silica glass which was used as a standard of comparison. A mirror attached to the ends of the two rods was tilted by the unequal expansions and the movement of the beam of light was registered photographically.

His data on tridymite, which show both the α-β_1 and the β_1-β_2 inversion expansions, are reproduced graphically in Fig. 4 together with those of Le Chatelier. The small circles represent Le Chatelier's original data. The dot-dash curve represents the one drawn by Le Chatelier to express these results. In his paper of 1913, however, he gives a curve whose locus is the solid curve of our Fig. 4, but does not indicate that any new experimental data were obtained. The small crosses and the dash-curve through them represent Braesco's data. The right hand set of curves represents the lower portion of the other set on a magnified scale.

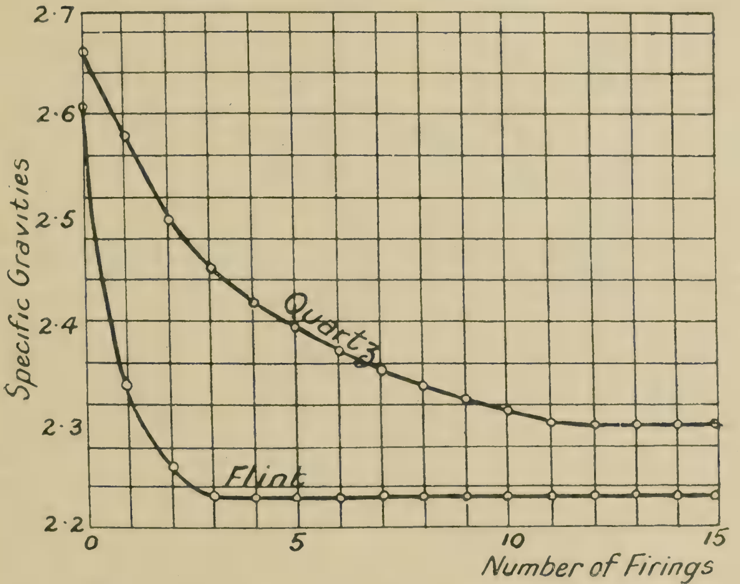

FIG. 3.—Effect of repeated calcinations upon the specific gravity of flint and quartz. After Mellor and Campbell.

Braesco's data on cristobalite will be discussed below in connection with our own.

Preparation of the Materials

8. The Flint.—The flint employed in our experiments was prepared from selected black European pebbles supplied for use in ball mills. The pebbles were first calcined at 1140°C and from the fragments thus obtained, pure white specimens were selected, crushed in a steel mortar, and finally pulverized in an agate mortar to pass 150 mesh. The powder was then washed with hot hydrochloric acid to remove iron and lime and after removing the acid with hot water, the powder was dried.

The purified powder thus obtained was calcined for two hours at 1430–1460°C in a gas-fired furnace, the total time of heating being four hours. The product of this calcination, after another washing with hydrochloric acid, was analyzed and found to contain 99.60 per cent SiO_2. Rieke and Endell's flint analyzed 98.7 per cent SiO_2, while that of Mellor and Campbell had 98.2 per cent SiO_2 in the raw state, but only 93.6 per cent after calcining and grinding, the impurities introduced being CaO, Al_2O_3 (4.6%) and alkalies (0.5%).

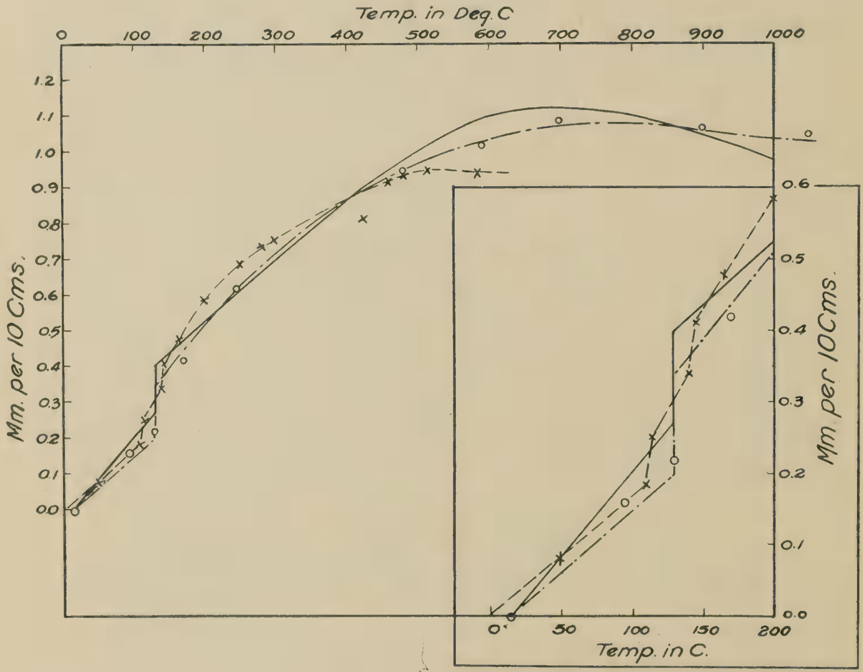

FIG. 4.—The thermal expansion of tridymite. After (1) Le Chatelier and (2) Braesco.

9. The Chalcedony.—The chalcedony was a very pure specimen obtained from the collection in the United States National Museum, its original source being the Yellowstone National Park. A thin section of the material showed the finely fibrous development characteristic of chalcedony, the white banded portions being composed of larger fibers than the gray, translucent interior. Selected portions of the wax-like interior were broken up and put through the same treatment as that employed with the flint. The final product was pure white and analyzed 99.87 per cent SiO_2. The chalcedony studied by Rieke and Endell contained 99.8–99.9 per cent SiO_2 after calcination.

10. The Tridymite.—The tridymite was prepared by calcining a mixture of 4 parts of the calcined flint with 1 part of sodium tungstate for 150 hours at 1300°C. The calcined mixture was then washed with hot water, followed by hydrochloric acid and ammonia as described by Fenner.[1] Microscopic examination showed the plate structure, the twinning, and the parallel extinction characteristic of tridymite. The index of refraction was 1.4750.

11. The Cristobalite.—The cristobalite was prepared in the same way as the tridymite, but with a 7-hour calcination at 1500°. Microscopic examination showed the characteristic skeleton-like forms described by Fenner. The index of refraction was higher than 1.4830.

The Specific Gravity Determinations

12. The Weighing Procedure.—The pycnometer shown in Fig. 5 was employed. Previously to placing it upon the balance pan the outside was wiped with a damp cloth. A glass counterpoise having the same superficial area was treated in the same way, and placed upon the opposite pan of the balance in all weighings, thus eliminating any errors due to variations in superficial moisture and ensuring a rapid attainment of equilibrium in the balance case. Readings of temperature, barometricpres sure, and humidity of the balance case were made in connection with every weighing and all weights were reduced to *vacuo*.

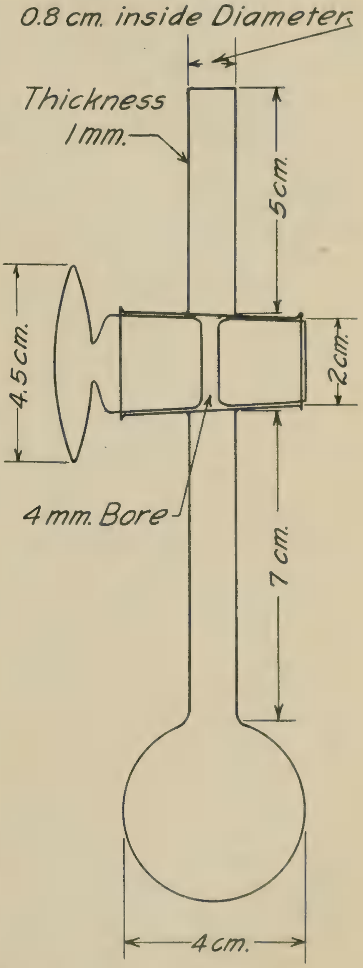

FIG. 5.—Pycnometer of pyrex glass.

13. Determination of the Weight of the Dry Powder.—The bulb of the pycnometer was filled with the powder with the aid of a funnel whose stem passed through the stop-cock to the bottom of the bulb. The pycnometer was then placed in position in the small electric furnace, *a*, and connected to the evacuating system as shown in Fig. 6. The furnace was slowly ($1^1/_2$ hours) brought up to 400°, kept there for one hour and then cooled (1 hour) to room temperature. Throughout this operation the vacuum pumps maintained a vacuum of better than 0.02 mm. in the pycnometer.

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[1] Fenner, *Trans. Soc. Glass Tech.*, **3**, 120 (1919).

By means of a drying train connected to *g*, air, dried by calcium chloride and phosphorus pentoxide, was then admitted to the pycnometer, after which its stop-cock was closed and it was disconnected and transferred to the balance case for the first weighing. The above operation was then repeated and the weighing checked.

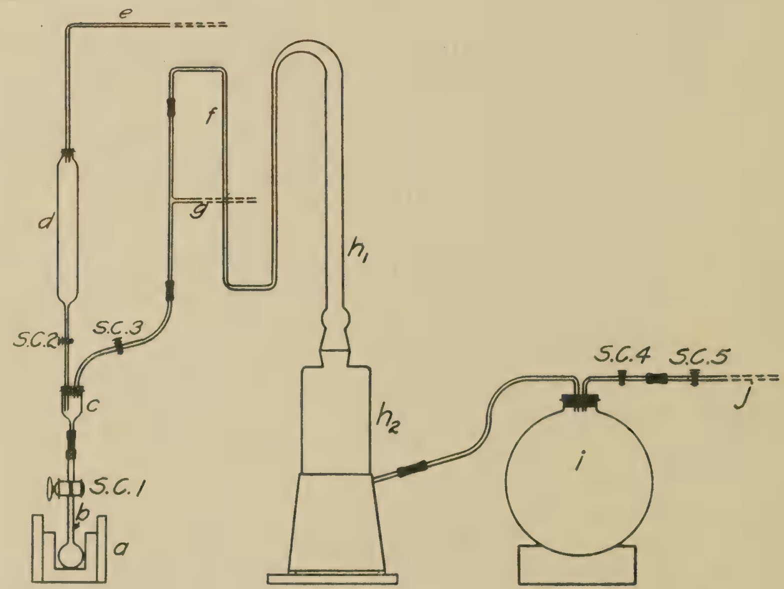

FIG. 6.—Illustrating the apparatus for evacuating and filling the pycnometer. *a*, electric furnace; *b*, the pycnometer; *d*, separatory funnel; *e*, connection to supporting pump; *g*, connection leading to McLeod gauge and to drying train; h_2, Langmuir mercury vapor pump; *i*, receiving flask; *j*, connection to supporting pump.

14. Adsorption of Air by the Powder.—In one experiment the pycnometer was removed without admitting air and weighed while evacuated in order to ascertain if there was any appreciable adsorption of dry air by the powder. The results showed that the adsorbed air could not have amounted to more than 0.01% of the weight of the powder.

15. Filling the Pycnometer with Water.—The pycnometer containing the dry powder was connected to the stem of a separatory funnel containing distilled water (*d*, Fig. 6). After evacuating the pycnometer and the stem of the separatory funnel (0.02 mm.), the water in the funnel was boiled *in vacuo* for 15 minutes and then admitted to the pycnometer by opening S. C. 2. When full, the pycnometer was removed to a constant temperature bath and allowed to come to equilibrium. The stop-cock was then closed and after removing the excess water above it and drying the outside, the pycnometer was transferred to the balance case and weighed. In the case of the determination at 0° the pycnometer, after removal from the ice bath, was first placed in a bath at room temperature and its stop-cock opened for a short time in order to permit the water to expand before weighing.

The thermometers used were compared with a standard certified by the National Bureau of Standards and all necessary corrections were applied. All temperatures in this paper are in degrees Centigrade.

16. Determination of the Volume of the Pycnometer.—This determination was carried out by the procedure just described. The determination was made both before and after the pycnometer had been subjected to the heat treatment described in Sec. 13 the results being 36.985 cc. and 37.005 cc. respectively. The latter value was used in the calculations.

17. The Results.—The following specific gravity values were obtained.

Calcined flint: $D^{25°}/_{25°} = 2.251$, $D^{25°}/_{4°} = 2.245$.

This result is lower than the values 2.27 and 2.33 which Fenner[1] found for tridymite and for cristobalite, respectively at $^{27°}/_{27°}$. Mellor and Campbell's values for calcined quartz and calcined flint are slightly lower than ours, the former being 2.32 and the latter 2.22, but they employed only the customary method of specific gravity determination, and the small difference might well have been due to the failure of their method to completely fill all fine cracks with the immersion liquid. It is evident that nothing but sealed pores or micro-pores could escape being filled by the method employed in our measurements. Mellor and Campbell's flint also contained considerable quantities of fluxing materials which might have influenced the result somewhat.

Calcined chalcedony: $D^{25°}/_{25°} = 2.175$, $D^{25°}/_{4°} = 2.169$, $D^{0°}/_{4°} = 2.174$, $D^{95°}/_{4°} = 2.172$. The result for room temperature is lower than any of the values (2.194 to 2.213) given for silica glass. Rieke and Endell found values even lower, ranging from 2.16 to 2.19 and Le Chatelier obtained the value 2.16 for his chalcedony calcined at 1500°. The values given in the literature for the specific gravity of silica glass vary from the value 2.194 found by Schwarz[2] to the value 2.213 found by Day and Shepherd,[3] the value ordinarily given being 2.20.

From our results at 0° and 95° it is evident that the expansion of calcined chalcedony over this temperature range is not appreciable. Thus in this respect also it resembles silica glass.

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[1] Fenner, *op. cit.*, p. 352.

[2] Schwarz, *Z. anorg. Chem.*, **76,** 423 (1912).

[3] Day and Shepherd, *Amer. Jour. Sci.*, **22,** 276 (1906).

18. Effect of High Pressures upon the Specific Gravity Results.—With the thought that the presence of micro-pores or cracks might possibly be the explanation of the apparent low specific gravity exhibited by the calcined chalcedony, it was deemed desirable to subject the immersed powder to high pressures to see if any additional water could be forced into it.

Eight grams of the powder were therefore removed from the pycnometer, transferred to a glass vial and the whole weighed while immersed in water. The vial containing the powder under water was then sent to the Geophysical Laboratory at Washington where it was placed in the high pressure machine and subjected, while immersed in water, to a pressure of 1000 atmospheres for two hours. After this treatment its weight in water was again taken and was found to have increased slightly, the increase being equivalent to a specific gravity increase of only six units in the fourth decimal place. The value 2.175_6 ($^{25°}/_{25°}$) must therefore be taken as the specific gravity of the material, which seems thus to be, without question, specifically lighter than ordinary silica glass.

19. The Effect of Fine Grinding.—The low value of the specific gravity of calcined chalcedony might obviously be due in part to the presence of numerous small *sealed* pores of microscopic or sub-microscopic dimensions. In order therefore, to test this hypothesis, a sample of the material was ground in an agate mortar and the finest particles were separated by stirring up the material with water and allowing it to settle for 48 hours. The milky supernatant liquid was then removed and evaporated to dryness at low temperature. When sufficient material had been obtained in this way, the average size of the particles was determined with a micrometer microscope and they were found to be 0.0023 mm. in diameter. The density of this material was then measured and found to be 2.224, an increase of 2 per cent over the previous value, thus showing definitely the presence of an appreciable volume of extremely small pore spaces.

This result is, we believe, the first instance of an appreciable effect of fine grinding upon the density of a mineral. The careful experiments of Johnston and Adams[1] upon the density of quartz powder of different degrees of fineness, down to particles smaller than 0.02 mm. led them to the conclusion that "When homogeneous material, free from cracks and holes, is powdered, the change of density thereby produced is but little greater than the error of the method employed. It may be noted, however, that the change, if real, is. . . .a *decrease;*. . . ." It is evident that the behavior of calcined chalcedony constitutes an exception to this conclusion unless submicroscopic pores are to be included in the term "holes."

[1] Johnston and Adams, *Jour. Amer. Chem. Soc.*, **34,** 572 (1912).

The Dilatometer Experiments

20. The Apparatus.—The dilatometer employed consisted of a bulb of pyrex glass 4 cm. in diameter and 10 cm. high with a capillary tube 100 cm. long and 1.93 mm. bore, ground into its neck. About 50–60 grams of the powder were placed in the bulb and the remaining space filled with a mixture of 95-per cent sulphuric acid with potassium sulphate, the specific gravity of the mixture at $^{25°}/_{25°}$ being 1.94. The capillary tube was then cemented into its socket and all enclosed air carefully eliminated. The heating arrangement is shown in Fig. 7.

21. The Heating and Cooling Curves.—The results of some of the dilatometric experiments are displayed in Fig. 8. These results will be discussed under the headings of the materials studied.

(*a*) *Tridymite.*—The cooling curves obtained with pure tridymite were smooth and almost straight throughout the complete range from 95° to 250°. The purity of the material was evidenced by the absence of any volume change in the α-β cristobalite inversion range. The simple method of heating or cooling curves proved to be not sensitive enough to show directly the small volume change which occurs at the α-β_1 tridymite inversion temperature. In order, therefore, to measure this volume change, the following procedure was adopted:

The dilatometer was filled with the sulphuric acid mixture (144.1 grams) and a slow cooling curve was taken over the tridymite inversion range. This curve was a perfectly straight line. From the known diameter of the capillary (1.93 mm.) and the weight of the mixture, the average volume change per gram per degree was calculated to be 26.0×10^{-5} cc. for the acid mixture, in glass.

The dilatometer was then filled with known weights of tridymite and of the acid mixture and readings taken when equilibrium was reached at 106.8° and 124.8°, respectively. Using the above factor for the expansion of the acid mixture, the expansion of the tridymite over this temperature range was calculated to be 93×10^{-5} cc. per gram. Then from the cooling curve of tridymite, its expansion was calculated to be $(3.8 \pm 0.8) \times 10^{-5}$ cc. per gram per deg., or (0.008 ± 0.002) per cent per deg., above its transition temperature and $(1.5 \pm 1.2) \times 10^{-5}$ cc. per gram per deg., or (0.003 ± 0.002) per cent per deg., below its transition temperature, 117°. From these values the purely thermal expansion between 106.8° and 124.8° was calculated to be $(30 \pm 6) \times 10^{-5}$ cc. per gram, whence by subtraction we find the volume increase for the inversion $\alpha \longrightarrow \beta_1$, to be $(63 \pm 6) \times 10^{-5}$ cc. per gram or (0.14 ± 0.01) per cent.

From Braesco's data[1] on the linear expansion of tridymite rods held together with sodium silicate we may also compute the coefficients of

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[1] Braesco, *op. cit.*

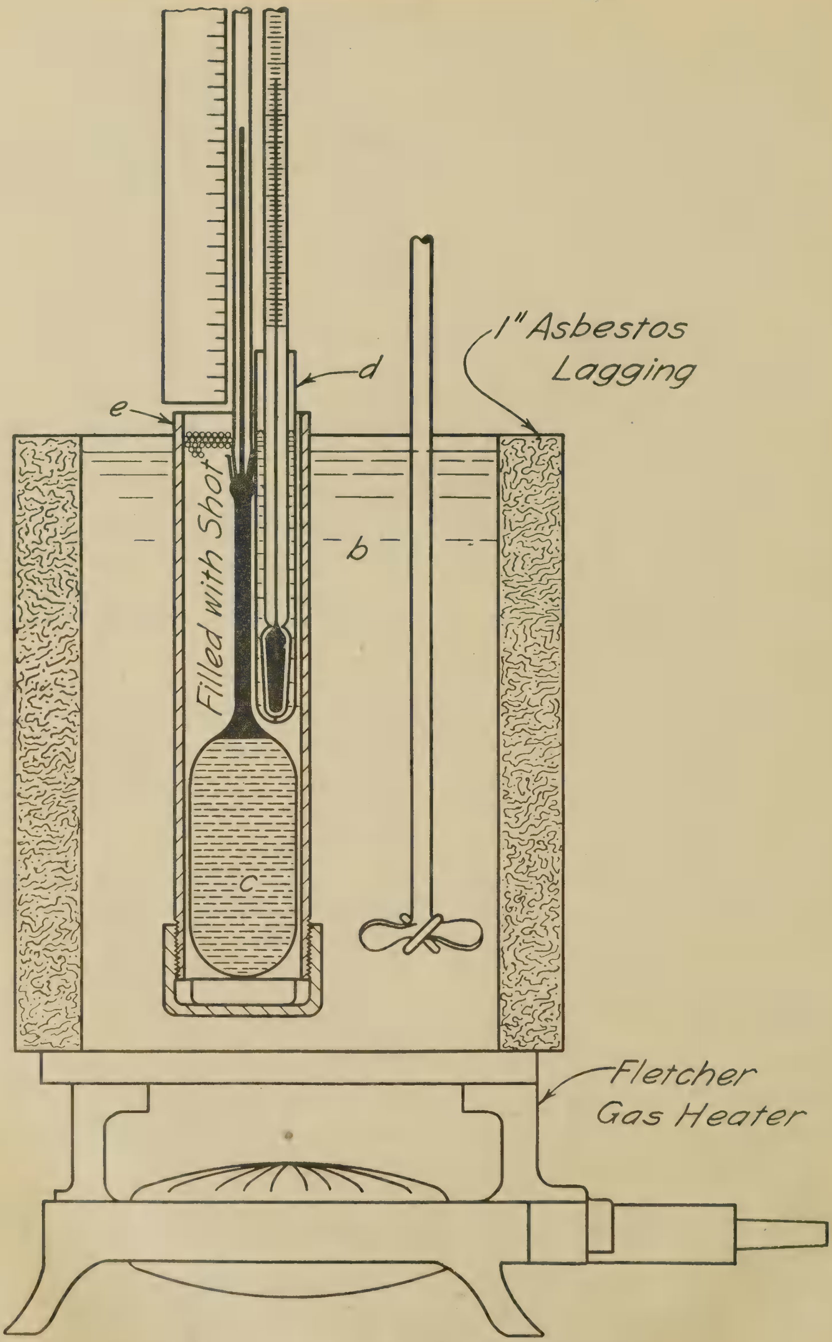

FIG. 7.—Dilatometer and heating arrangement.

cubical expansion and the volume increase on inversion. The values so computed together with our own are shown in Table I. The agreement is as good as could be expected.

(*b*) *Cristobalite.*—The cooling curves for cristobalite and for the acid mixture alone, over the same range, are shown in Fig. 8. From these curves the total expansion of the cristobalite between 198° and 251° was found to be 0.0198 cc. This expansion is made up of the ordinary thermal dilation plus the volume increase which accompanies the inversion. From the data obtained the coefficient of expansion of the β cristobalite between 235° and 251° was computed to be $(1.5 \pm 0.4) \times 10^{-4}$ cc. per gram per degree, or (0.032 ± 0.008) per cent per degree and that of α cristobalite between 198° and 205° (1.1 ± 0.5) 10^{-4} cc. per gram per degree, or (0.024 ± 0.011) per cent per degree.

If we call the point of inflexion, (229°), in the time-height curve, the "inversion temperature," then from the data obtained, the inversion expansion for this temperature is found to be 132×10^{-4} cc. per gram, or about 2.83 per cent.

Similarly from Braesco's data we may compute the coefficients of cubical expansion and the volume increase on inversion. These results together with our own are shown in Table I. With the exception of the value for β cristobalite, these results agree with ours within our experimental errors.

(*c*) *Quartz.*—Pulverized quartz sand was employed. The results are shown in Fig. 8.

(*d*) *Silica Glass.*—Fig. 8 shows the cooling curve obtained with 60 grams of powdered transparent silica glass and 91.7 grams of the acid mixture. From the curve for the acid mixture alone two points representing the expansion of 91.7 grams of the acid mixture between 186° and 225° were computed and marked on the curve for silica glass. It will be seen that these two points fall practically upon the cooling curve for silica glass which should, of course, be the case, if the expansion of the silica glass is negligible.

(*e*) *Calcined Flint and Calcined Chalcedony.*—The cooling curves of both materials were perfectly linear up to 180°. Between this temperature and 215° a marked increase in volume takes place, with both materials. The cooling curves are shown in Fig. 8 and the expansion data in Table I.

Since Fenner has shown that the inversion temperature of cristobalite depends upon the source and previous heat treatment of the sample under investigation, it is evident that we must conclude that calcined flint and chalcedony both exhibit the cristobalite inversion. This agrees with the conclusion reached by Rieke and Endell based upon dilatometric experiments in which a dilatometer with a 5 cc. bulb was employed. They found a break at 228° in the cooling curve of their calcined flint which agrees well with our value, 227°. Further details are not given.

The Inversion Temperatures

22. Thermal Analyses of the Materials.—Qualitative thermal analyses were made on the materials to determine the temperature at which the inversions take place. A suitable test tube, filled with the material in which the bulb of a thermometer was imbedded, was placed in the iron cylinder of the dilatometric set-up and well insulated. Cooling curves were then taken. The results follow.

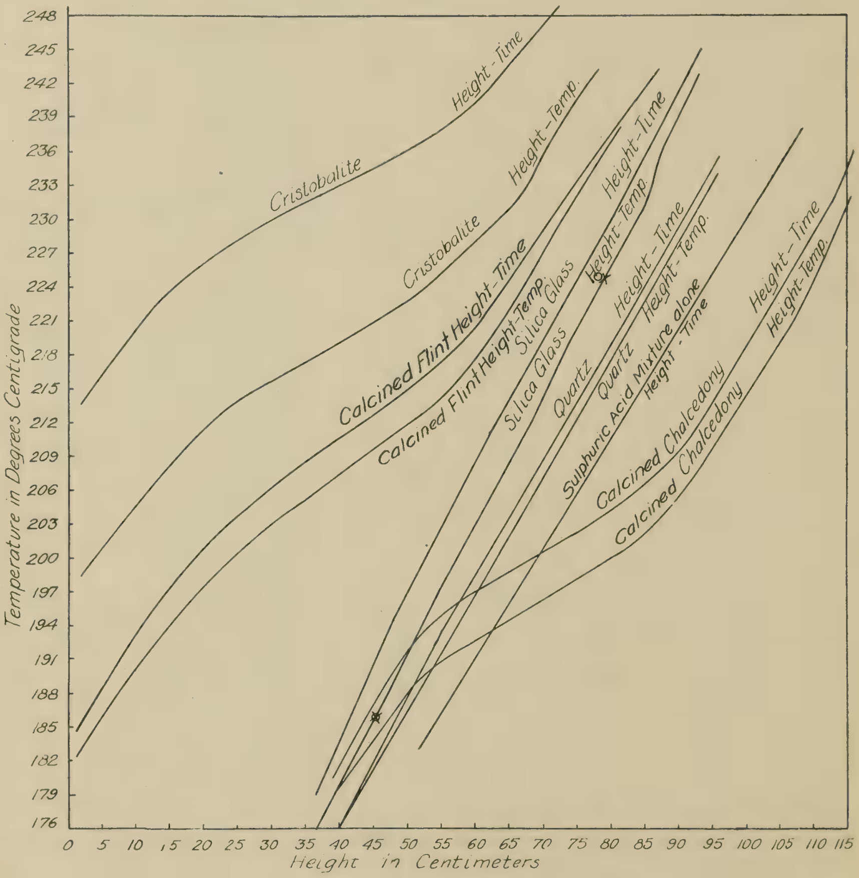

FIG. 8.—Cooling curves.

(*a*) *Tridymite.*—The range, 105°–138°, yielded only a smooth curve, showing that the heat of reaction at the inversion was exceedingly small.

(*b*) *Cristobalite.*—The inversion started at 244°. The change of slope is very evident, see Fig. 9.

(*c*) *Calcined flint.*—Fig. 9 shows an inversion starting at 227°.

(*d*) *Calcined chalcedony.*—An inversion starting at 220° is shown in Fig. 9.

Indices of Refraction

23. Method.—The indices of refraction of the powdered materials were measured with the petrographic microscope, using the Becke line method. The distinction between tridymite and cristobalite was made by means of a liquid of index, 1.4784.

24. Results.—The results are shown in Table I. In each instance *all* of the material fell within the index limits given.

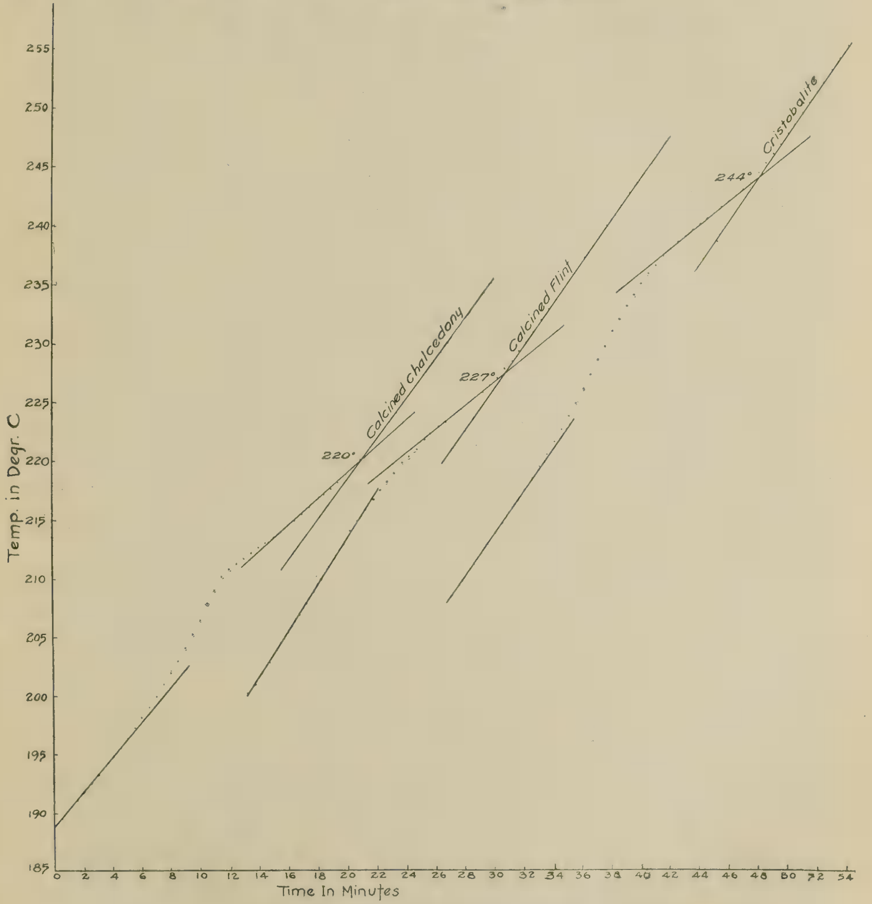

FIG. 9.—Thermal analysis curves.

Rieke and Endell's microscopic examination[1] of their materials did not include a determination of the refractive index. They state merely that thin sections of their calcined materials when examined with crossed Nicols appeared to be *completely isotropic*, but that under the highest magnification certain spots seemed to be anisotropic.

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[1] Rieke and Endell, *op. cit.*, p. 69.

25. Some Miscellaneous Experiments.—A small quantity each of the raw flint and the raw chalcedony was dropped into a platinum crucible and heated before a blast lamp for one minute and the index of refraction then measured. The raw flint after this treatment gave 1.500–1.519 and the chalcedony 1.500–1.526. Just what these values signify is not clear.

In a second experiment some of the raw flint was maintained at a temperature of 830° for 700 hours, one sample being drawn at the end of 1½ hours and another sample at the end of each 24 hour period. All of the samples drawn gave the same index of refraction, namely, 1.500–1.519 which is also the value obtained in the one minute experiments just described.

A sample of chert (?) obtained from deposits in the neighborhood of Tamms in the southern part of the State of Illinois was calcined at 1450°C for a few hours and its index measured. The following results were obtained: Raw "Joynt's" Silica, 1.542–1.550; calcined material, 1.478–1.493. The raw material thus has the index of quartz and the calcined material that of cristobalite.

The Significance of the Results

26. Comparative Summary.—In Table I the results obtained for raw and calcined flint and chalcedony are summarized and compared with the corresponding data for silica glass, cristobalite, tridymite and quartz.

A study of the data given in the table brings out the following facts: (1) The density of raw flint and chalcedony is appreciably lower than, but close to, that of quartz, the difference being not greater than that which might possibly arise from the presence of moisture and other impurities in the raw material. The density of the calcined flint is slightly lower than, but close to that of tridymite. The density of the calcined chalcedony is distinctly lower than that of silica glass, the lightest known form of silica.

(2) The indices of refraction of the raw flint and chalcedony are substantially the same and while close to that of quartz are distinctly lower. The index of the calcined flint is close to that of cristobalite, while the index of the calcined chalcedony is definitely lower than those of cristobalite and tridymite but agrees very well with that of silica glass. As far as these two properties are concerned, therefore, the calcined chalcedony might be considered as a form of silica glass, while the calcined flint might be either cristobalite or tridymite.

(3) Both the calcined flint and the calcined chalcedony exhibit a typical α-β cristobalite inversion.

The net result of the investigation thus far seemed to be that calcined chalcedony was either a new form of cristobalite with a density and index of refraction different from ordinary cristobalite or else that it was a form

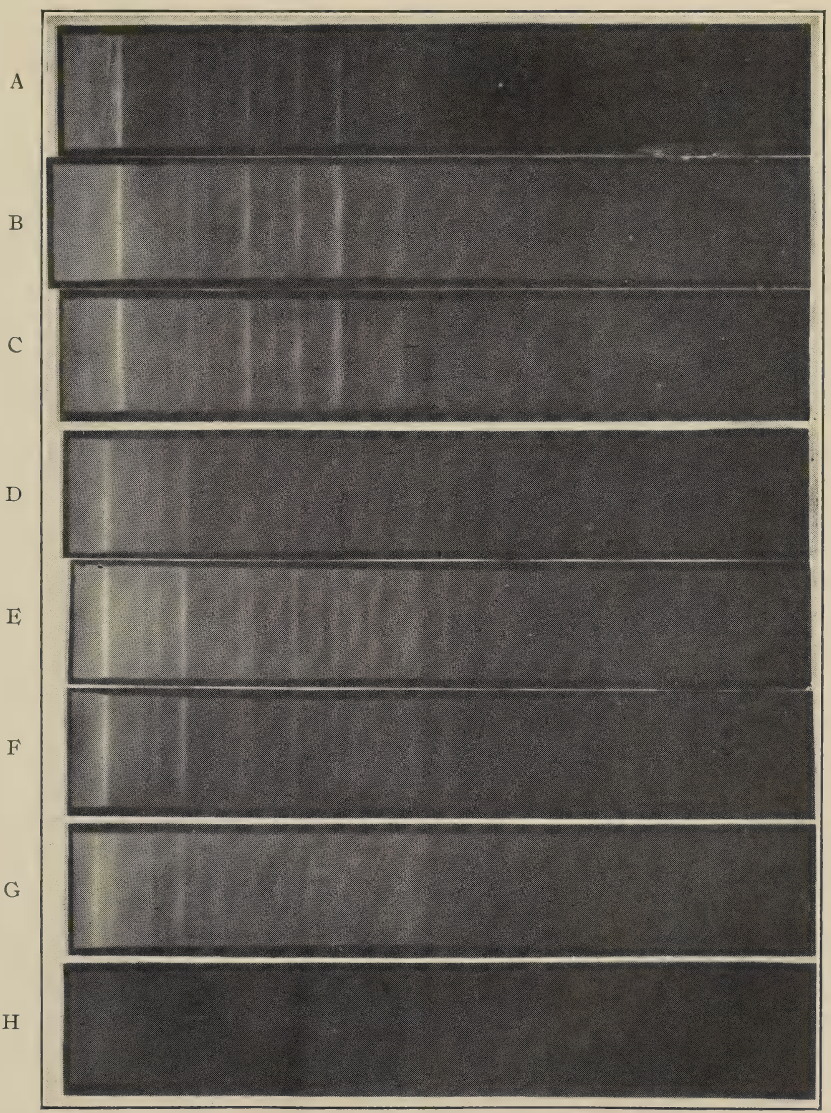

Fig. 10*a*.—X-ray crystal spectra.

A, quartz crystal; B, raw flint; C, raw chalcedony; D, cristobalite; E, calcined flint; F, calcined chalcedony; G, tridymite; H, silica glass.

of amorphous silica (silica "glass") which exhibited enantiotropism. In order, therefore, to determine (1) whether the material was crystalline or amorphous and (2) if crystalline, the species of crystal present, recourse was had to the method of X-ray crystal analysis described in the next section.

X-Ray Spectra

27. The Method of X-Ray Crystal Analysis.—When a narrow beam of monochromatic X-ray is passed through a powdered crystalline material the rays are diffracted by the layers of molecules on the various crystal surfaces, and if the diffracted rays are received upon a photograph plate, a spectrum of lines and bands of various intensities is obtained. The number, positions, and intensities of these lines are characteristic for each species of crystal. This method, originated by Laue and modified and improved by Bragg and Bragg,[1] Hull,[2] Debye and Scherrer, and Clark and Duane,[3] is, especially in the form devised by Hull, a new and valuable research tool which should find important application in ceramic investigation.

28. Results.—Through the coöperation of the General Electric Company we were enabled to secure the X-ray spectra of all of our materials. These spectra were photographed for us by Dr. A. W. Hull and are reproduced in our Fig. 10.

An examination of these spectra shows beyond question (1) that raw flint and raw chalcedony are made up of, or contain in considerable quantity, quartz crystals and (2) that calcined flint and calcined chalcedony are made up of, or contain in considerable quantity, cristobalite crystals and no other crystals of any kind.

Conclusions

29. The Nature of Flint and Chalcedony.—Based upon the results obtained in this investigation, the following theory concerning the nature of flint and chalcedony and their calcination products is proposed. This theory successfully correlates all the known facts concerning these materials.

(1) Flint and chalcedony consist of colloidal quartz. In the purer forms of chalcedony the colloid is of the gel type and the individual colloidal particles are microscopic or sub-microscopic in size.

Fenner[4] found that when chalcedony was heated in contact with a flux at 800°, "quartz" and tridymite were produced. The "quartz,"

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[1] Bragg and Bragg, "X-Rays and Crystal Structure." Bell and Sons, London, 1915.

[2] Hull, *Jour. Amer. Chem. Soc.*, **41,** 1168 (1919).

[3] Clark and Duane, *Proc. Natl. Acad. Sci.*, **8,** 90 (1922).

[4] Fenner, *loc. cit.* See footnote No. 1.

i. e., macrocrystalline quartz is evidently the result of the solution and recrystallization of the colloidal crystals, and quartz is of course, the stable form at this temperature. The simultaneous appearance of the metastable tridymite under such conditions is a common phenomenon. On long continued heating the tridymite should, of course, disappear.

Doelter[1] also records the simultaneous formation of quartz during the synthetic production of chalcedony at low temperatures, and its occurrence in nature closely associated with chalcedony is well known.

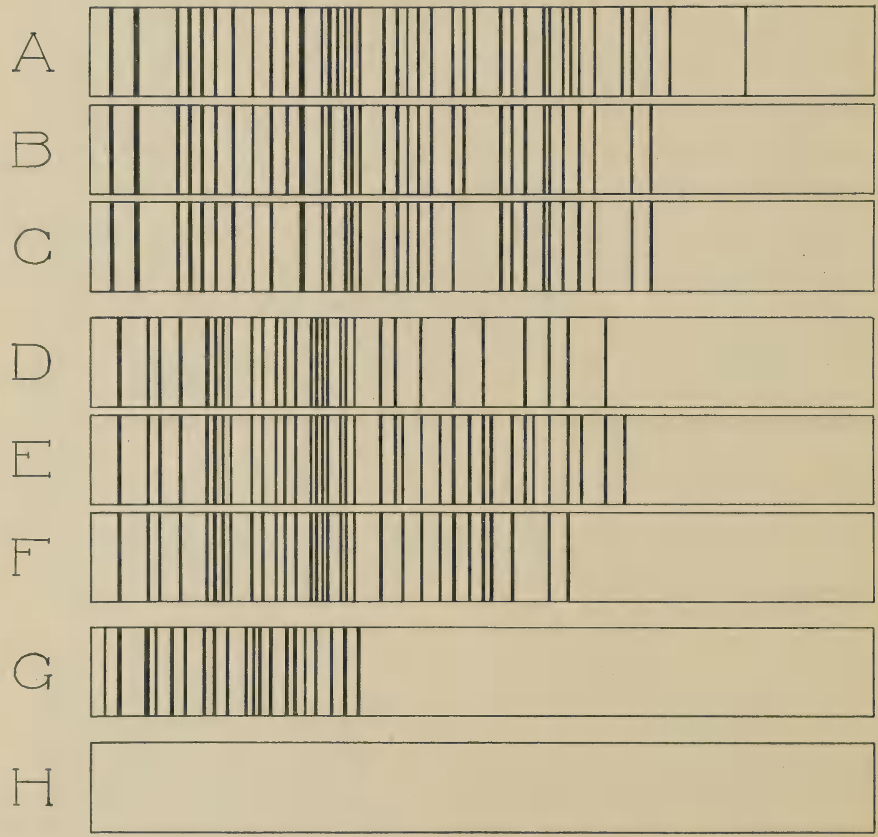

Fig. 10*b*.—X-ray crystal spectra.

A, quartz crystal; B, raw flint; C, raw chalcedony, D, cristobalite; E, calcined flint; F, calcined chalcedony; G, tridymite; H, silica glass.

(2) When calcined, the colloidal quartz crystals are, owing to the enormous surface which they expose, very rapidly transformed into cristobalite crystals. This is also the behavior of ordinary quartz, but with

[1] Doelter, "Handbuch der Mineralchemie," 2, II, 175.

this material the rate of conversion is much slower. In the case of the flint, the impurities present act as a flux and thus permit the formation of larger crystals of cristobalite than in the case of the purer chalcedony. The properties of the calcined flint, therefore, approach more closely those of ordinary cristobalite than is the case with the calcined chalcedony. The latter material is so pure that the colloidal quartz particles are transformed in *situ* into colloidal cristobalite particles. The comparatively large volume increase which accompanies this transformation produces small cracks and fissures between the colloidal particles and the simultaneous expulsion of volatile impurities, such as water, perhaps leaves numerous micropores throughout the mass.

At the same time some of the original colloidal quartz crystals, that is, the smaller ones, probably melt since the melting points of many of them must be considerably lower than that (<1470°) of ordinary quartz. This "melting" is not, however, accompanied by any appreciable fluidity since silica glass at this temperature is still a fairly rigid solid. The silica glass thus produced would, of course, immediately proceed to crystallize slowly, with the formation of colloidal cristobalite crystals. Lord Rayleigh[1] found that ordinary silica glass exhibits between crossed Nichols a quasi crystalline structure. These crystals, or incipient crystals, probably represent the first stages of the orientation of the silica molecules into the cristobalite groupings and silica glass held for some time at 1400–1500°C and then finely powdered should be substantially the same material as finely powdered calcined chalcedony. Both materials would consist principally of colloidal cristobalite together with a small amount of amorphous silica or silica glass, the relative proportions of the two depending upon the conditions of calcination.

(3) Since there must be a gradual gradation of properties extending all the way from those of isotropic silica glass on the one hand up to macrocrystalline cristobalite on the other, depending upon the degree of dispersion, it is clear that the low index of refraction and low density of the calcined chalcedony are readily understandable on the theory here proposed. A crystal composed of a comparatively small number of molecules, especially if not well formed, must be more or less distorted by forces of the nature of surface tension and corresponding changes in its refractive index are to be expected. Moreover, the exact significance of the refractive index (as measured by the immersion method) in the case of a material containing a considerable quantity of crystals too small to be resolved by the microscope is somewhat uncertain. The results of this method applied to the calcined chalcedony gave index values for different portions of the field ranging from that of silica glass, 1.456, up to 1.470. There were apparently no macrocrystals of cristobalite present. With the cal-

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[1] Lord Rayleigh, *Nature*, **104**, 153 (1919).

TABLE I

SUMMARY OF RESULTS

Results in black face type were obtained in this investigation. After calcination at 1450° for 2 hours the chalcedony analyzed 99.87 and the flint 99.6% SiO_2. Inversion temperatures were obtained from cooling curves and volume changes with a dilatometer

	Raw chalcedony	Raw flint	Quartz		Calcined chalcedony		Calcined flint		Cristobalite		Tridymite		Silica glass
			α		α	β	α	β	α	β	α	β_1	
Specific gravity, 25°/25°	2.55–2.61	2.61–2.63	2.65	. . .	2.175	. . .	2.25	. . .	2.33	. . .	2.27	. . . .	2.194–2.213
Index of refraction	1.533–1.538	1.533–1.539	1.544–1.553	. . .	1.456–1.470	. . .	1.483	. . .	1.484	. . .	1.475	. . . .	1.457–1.460
Inversion temperature, t_1			575°	570°	. . .	220°	. . .	227°	. . .	244°	117°	. . . .	None
Coefficient of cubical expansion near t_1													
(*a*) Cc. per gram per deg. × 10^4	. . .	. . .	0.25	−0.049	1.3±0.3	1.4±0.2	0.9±0.4	1.4±0.3	1.1±0.5	1.5±0.4	0.15±0.12	0.38±0.08	. . .
(*b*) Per cent per degree × 10^2	. . .	. . .	0.65	−0.12	2.7±0.6	2.8±0.4	1.9±0.8	3.0±0.6	2.4±1.1	3.2±0.8	0.3±0.2	0.8±0.2	. . .
(*c*) Ditto, from Braesco's data	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	1.6	0.65	0.53	1.0	. . .
Volume increase on inversion $\alpha \longrightarrow \beta$ at t_1													
(*a*) Per cent	. . .	. . .	2.16		2.63		3.09		2.83		0.142		. . .
(*b*) Ditto, from Braesco's data	. . .	. . .	. . .		. . .		. . .		2.4		0.2		. . .
(*c*) Cc. per gram × 10^4	. . .	. . .	84		131		150		132		6.3±0.6		. . .

cined flint on the other hand practically all of the material was in the form of macrocrystalline cristobalite.

(4) Fenner made a thermal analysis of raw chalcedony over the quartz α-β inversion temperature and failed to find any heat effect indicating an inversion at this temperature. It was largely because of this negative result that he concluded that chalcedony could not be classified as quartz. Now it is altogether probable that both the inversion temperature and the heat of inversion of a quartz crystal vary markedly with the size of the crystal, for crystals of colloidal dimensions. Consequently, according to our theory of the nature of raw chalcedony, we might expect that the quartz inversion would be spread over a considerable range of temperature owing to the varying sizes of particles present and this inversion might, therefore, easily fail to be detected by the method of thermal analysis. It ought, however, to manifest itself in a dilatometer owing to the large volume change which accompanies the inversion.

30. Acknowledgments.—Through the good offices of Professor T. T. Quirke of the Department of Geology, we were able to secure an excellent sample of chalcedony. This sample was supplied by Dr. G. P. Merrill of the United States National Museum and proved to be an extremely pure material.

To the Geophysical Laboratory of the Carnegie Institution of Washington and especially to Dr. H. L. Adams of that laboratory we are indebted for the high pressure test which was applied to a sample of our material during the course of the work.

To Dr. A. W. Hull of the Research Laboratory of the General Electric Company we are especially indebted for the photographs of the X-ray spectra of the materials. Without these spectra it would have been impossible to bring the investigation to a satisfactory conclusion, since the usual methods of measurement failed to yield a definite solution of the problem.

The experimental data contained in this paper were obtained by the junior author in connection with the preparation of a thesis submitted by him to the Graduate School of the University of Illinois in partial fulfilment of the requirements for the degree of Master of Science in Ceramic Chemistry, in June 1921.

Department of Ceramic Engineering
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Urbana, Ill

AN IMPROVED MAGNET BOX[1]

By H. Spurrier

ABSTRACT

The plates are made of wrought iron carrying vertical projections, thereby carrying the magnetic poles clear up into the flowing slip.

The slip is broken up into several streams which, on passing the narrow spaces between the fingers, more readily yield their metallic iron.

Settlings in the box do not impair the magnetic efficiency.

During a siege of iron spots in white ware, several lines were investigated as likely contributory causes of our trouble, but still iron spots were discouragingly frequent.

Among other things which were done, one in particular seems worthy of wider application as time has now proven its real utility.

An effort was made to increase the efficiency of the magnet box. The box in question was equipped with malleable cast iron plates, provided with projections of about $^5/_{16}$ of an inch, which usually lay buried in the deposit of coarse particles which commonly collect in the box until removed. This deposit, even when very slight, was found to seriously impair the efficiency of the magnet.

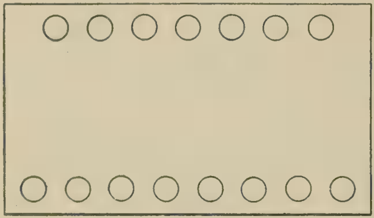

Fig. 1.

It was known that the magnetization was 80 per cent higher for wrought iron than for malleable iron and accordingly the malleable plates were replaced with wrought iron plates. So great was the improvement that a rough and ready attempt to measure the difference was made. A piece of one-inch wrought iron pipe, a trifle shorter than the width of the magnet box, was provided with a loop of cord through it, long enough to pass over the top of a postal scale held by hand. On gradually forcing the scale upward, the pressure necessary to overcome the pull of the magnet could be read off the dial of the scale. After repeating this a few times, the readings became more constant.

Under the same conditions of magnetic induction, the malleable iron plates required a pull of three and one-half pounds, and the wrought iron plate six pounds to break contact, an increase of 71+ per cent.

A further improvement of more marked effect, as regards the efficiency of the magnet, was worked out. The finer particles of metal in a viscous fluid, such as slip, are little influenced at even a very small distance from an excited pole. It was thought that if, at the ends of the wrought iron plates, fingers were to project upward to a height equivalent to the depth of the slip in the magnet box, much good would ensue, because the fingers

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[1] Received June 5, 1922.

would then become the pole terminal and would carry the most powerful part of the magnetic field into the slip itself. Other advantages are that the fingers break up the body of slip which must pass between them, and that the settlings do not cover the best part of the field.

The effects of these changes were quite remarkable as the fingers being staggered caused the slip to flow in a sinuous passage along the magnet box.

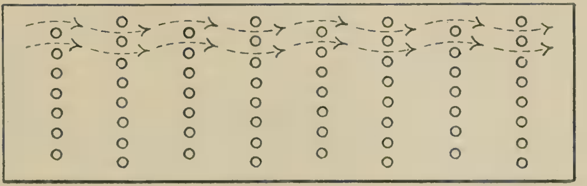

Fig. 2.

Fig. 1 is a plan of the plate, the direction of flow being transverse to the actual length of the plate.

Fig. 2 is a plan of the magnetic box indicating the sinuous course taken by the slip as it is divided by the fingers. This course is not imaginary but is very evident when the slip is flowing.

In the first trial only one plate was put in with the fingers, the result, however, was so good that a full set was made up and has been doing excellent work for nearly a year.

Square D Co.
Peru, Ind.

THE CONTROL OF BISCUIT LOSSES[1]

By Ira E. Sproat

ABSTRACT

The effect of the transverse strength and the moisture content of the body on biscuit losses is discussed. A transverse strength of 280 pounds per square inch and minimum moisture content produce the best results.

The analysis of the damaged ware and the brushers report gives data of great value in decreasing the biscuit losses, under given factory conditions.

Introduction

The subject of biscuit loss and its control is one of great importance to the average general ware manufacturer; especially is this true during the present period of keen competition and the downward trend of selling prices.

The Human Element.—Perhaps the most important factor affecting the biscuit losses is the "Human Element." It has become increasingly important during the last five years due to the demand for production. But one needs only to read the discussion of Herford Hope's paper on "Biscuit Losses"[2] to learn that the "Human Element" was also a very important factor in 1906 as it now is. In fact it will always be an important factor. It is quite evident, therefore, that any method of control must take the "Human Element" very largely into consideration if it is to prove of any value.

After trying a number of different methods of control during the year 1919, we finally decided on the following three-fold control:

1. Transverse Strength of Body in the Clay State.
2. Biscuit Loss Analysis.
3. Analysis of Brushers Report.

During the past two years this method has been followed closely and we are certain the results have justified its use.

Transverse Strength of Body

It has always been a well known fact by potters that one of the best ways to decrease the biscuit losses is to increase the amount of ball clay in the body. The strength of the body in the clay state is thus increased and the effect of careless handling of the ware (the Human Element) decreased. There is, however, no published data on the relative effect of the varying strengths of bodies upon the biscuit losses. We thought it advisable to determine the modulus of rupture of our body for a period of several years and then compare these results with the biscuit losses for the same period, in order to determine what relation the one had to the other.

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[1] Received May 10, 1922.

[2] *Trans. Amer. Ceram. Soc.*, **8**, 62, 1906.

Transverse strength tests of the body direct from the pug mill were made twice a week, the average of these two tests being taken as the weekly value. The results of these tests for the past three years are shown on the upper curve of the accompanying curve sheet.

The biscuit loss in per cents is also given for the same period on the same curve sheet; the fine dotted line represents the daily losses, while the lower heavy line, the weekly averages.

When studying these curves it must be remembered that the modulus of rupture curve is several weeks in advance of the biscuit loss curve, due to the time required to make the ware and put it through the biscuit kiln.

From the 22nd week of 1919 to the 30th week in 1921 inclusive the following body was used:

Flint	34.0%
Feldspar	14.0
Edgars Florida	7.5
English China Clay	27.5
English Ball	17.0
	100.0

The great variation in strength of this body during the above period was due to the use of several kinds of English Ball clays and also to marked variations in the physical properties of different shipments of the same clay.

Specific attention is called to the high strength (300 pounds per sq. in.) of the body during the latter part of 1921. This was due to the substitution of 21% of "Hercules" clay for a portion of the English Ball and China clays in the formula just given. The maximum transverse strength obtained with English clays was only 260 pounds per square inch. Perhaps greater strengths could be obtained with these clays but color would have to be sacrificed and warpage would be materially increased.

From a study of the modulus of rupture and biscuit loss curves it can be readily seen that the *biscuit losses decrease with every marked increase in strength up to 300 pounds*, and *vice versa*. Therefore, decided changes in the modulus of rupture of a body is a sure indication that there will be an inverse change in the biscuit losses within a week or so, all other factors being equal.

From a further study we see that a modulus of rupture of 200 pounds will give a biscuit loss of about 7.0%; 225 pounds, a loss of about 6.0%; 250 pounds, a loss of 5.0%; 275 pounds a loss of 4.0%; and 300 pounds, a loss of about 3.5%. In other words the biscuit loss can be decreased about 1.0% by increasing the transverse strength 25 pounds per square inch, or 2.0% by a 50 pound increase in the strength, etc.

We also found that a *body with a modulus of rupture of over 300 pounds* *had poor working qualities.* It was too tough to flow readily when batted out or when formed into a piece of ware by the jiggerman, therefore, causing a greater biscuit loss than in a body having less strength.

The writer is of the opinion that a modulus of rupture of 280 pounds per square inch will give the best results under all conditions of manufacture. It must be remembered, however, that under some factory conditions, especially in those plants where quantity production is of secondary consideration, a modulus of rupture of 280 pounds will produce a biscuit loss far below the 3.5% noted above. In other words in those factories where more time and care is taken in handling the ware, a biscuit loss of 1.0% to 2.0% is no mere dream.

Moisture Content

Another factor to be considered is the amount of moisture the ware contains when it is removed from the molds. For a piece of ware which has a transverse strength of 300 pounds per square inch in the bone dry state, has a strength of only about 180 pounds when it contains from 3.0% to 10.0% moisture. All the moisture therefore would be expelled from the ware before it is handled.

Since very little ware being made today contains less than 3.0% of moisture, there is a great need for improved types of stove rooms in the general ware industries.

Biscuit Loss Analysis

Any method devised for the purpose of analyzing the damaged ware from the biscuit kilns, must necessarily meet the following three principal requirements.

First.—It must not require too much time as it is advisable to make an analysis daily. All the damaged ware from the kilns can not be inspected daily, as this would require too much time. Only one class of ware should be analyzed daily.

Second.—The analysis should be made on that class of ware which is coming through the kilns daily in large quantities and in which the biscuit loss is the highest on the average. Seven-inch plates fill these requirements.

Third.—The classification of the various types of damages should be such that there would be no question as to how the damaged piece should be classified. After careful study and testing for months we have found the following classification satisfactory for this analysis:

1. Nipped
2. Warped
3. Rim Cracked
4. Foot Cracked

5. Bottom Cracked
6. Dunted
7. Sympathetic Dunts

The above classification may be further simplified by combining 3, 4 and 5 into one group called clay cracks.

It is not the purpose of this report to discuss the great number of different types of cracks and their causes, but in order that the reader may more fully understand the above classification a brief description of each type is given.

1. Nipped.—A piece of ware is classed as "nipped" if it is not cracked or warped. Cause.—Careless handling.

2. Warped.—All ware not cracked but warped is classed in this group. Cause.—Too high a ball clay content, too high and rapid firing.

3. Rim Cracked.—A piece of ware is classified under this heading if the crack is wider at the rim of the plate than in any other portion. Cause. —Too weak a body: Careless handling.

4. Foot cracks.—Cracks which show a greater width at the foot of the piece of ware are called footcracks. Cause.—Too weak a body, or careless handling; too green when taken off molds.

5. Bottom Cracked.—A plate which is cracked in the bottom is classed in this group. Cause.—Too weak a body; careless handling, or too green when taken off the molds.

6. Dunted.—A piece of ware is classed as dunted when it shows a fine circular hair line crack and the entire surface of the crack is smooth. Cause.—Too rapid cooling.

7. Sympathetic Dunts.—All ware which shows the characteristic circular hair line crack of a dunt but the entire surface of the cracked portion is not smooth are classed as sympathetic dunts. Cause.—Too weak a body: poor pugging: occluded air: careless handling.

The damaged seven inch plates, thrown out by the brushers, are inspected and sorted according to the above classification. The number in each of the seven groups is counted and recorded as percentages of the total number of plates brushed.

But such data would be of very little value unless we had some way of knowing when we were having an excessive loss from one of the above causes. This brings us to the consideration of the normal percentage for each of the above classifications.

Normal Percentages.—The normal percentages which we found to apply to our factory conditions during 1919, 1920 and the first half of 1921 are given in the following table.

The method used in obtaining these figures was as follows: Over 10,000 damaged seven inch plates, taken from burns in which the loss was normal, were inspected and classified, the average figure taken as the normal.

These normal percentages are nothing more or less than a guide by which we are able to tell when we have an abnormal loss in any one of the above groups, and thereby determine the cause in the shortest possible time.

Nipped	0.577%
Warped	0.534
Rim cracked	1.138
Foot cracked	0.418
Bottom cracked	0.314
Dunted	0.957
Sympathetic dunts	1.562

An analysis of the damaged seven inch plates from a given burn is as follows:

Nipped	0.731%
Warped	0.522
Rim cracked	1.164
Foot cracked	0.400
Bottom cracked	0.328
Dunted	2.100
Sympathetic dunts	1.495

By comparison against the normal percentages, it is seen that the percentages of nipped ware and dunted ware are too high in this burn.

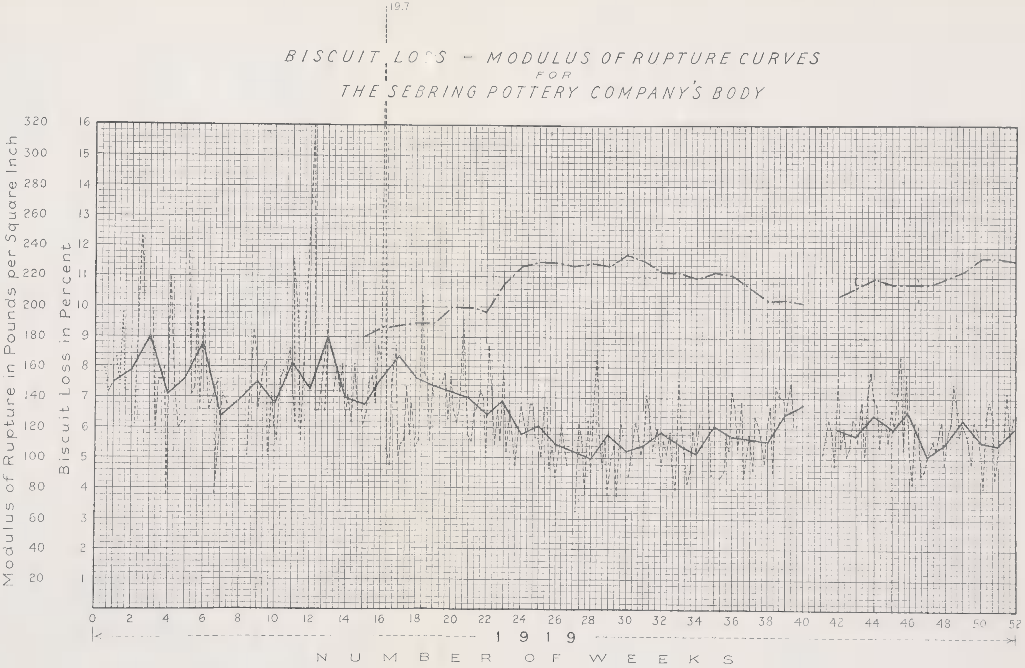
It must be remembered that the above normal percentages apply only to the conditions under which they were obtained, and may not apply to any other factory. As a matter of fact conditions in the same plant may be so changed as to materially affect these normal figures as was the case during the last half of 1921, when a radical change was made in the body composition. The normal percentages in use now with this new body are as follows:

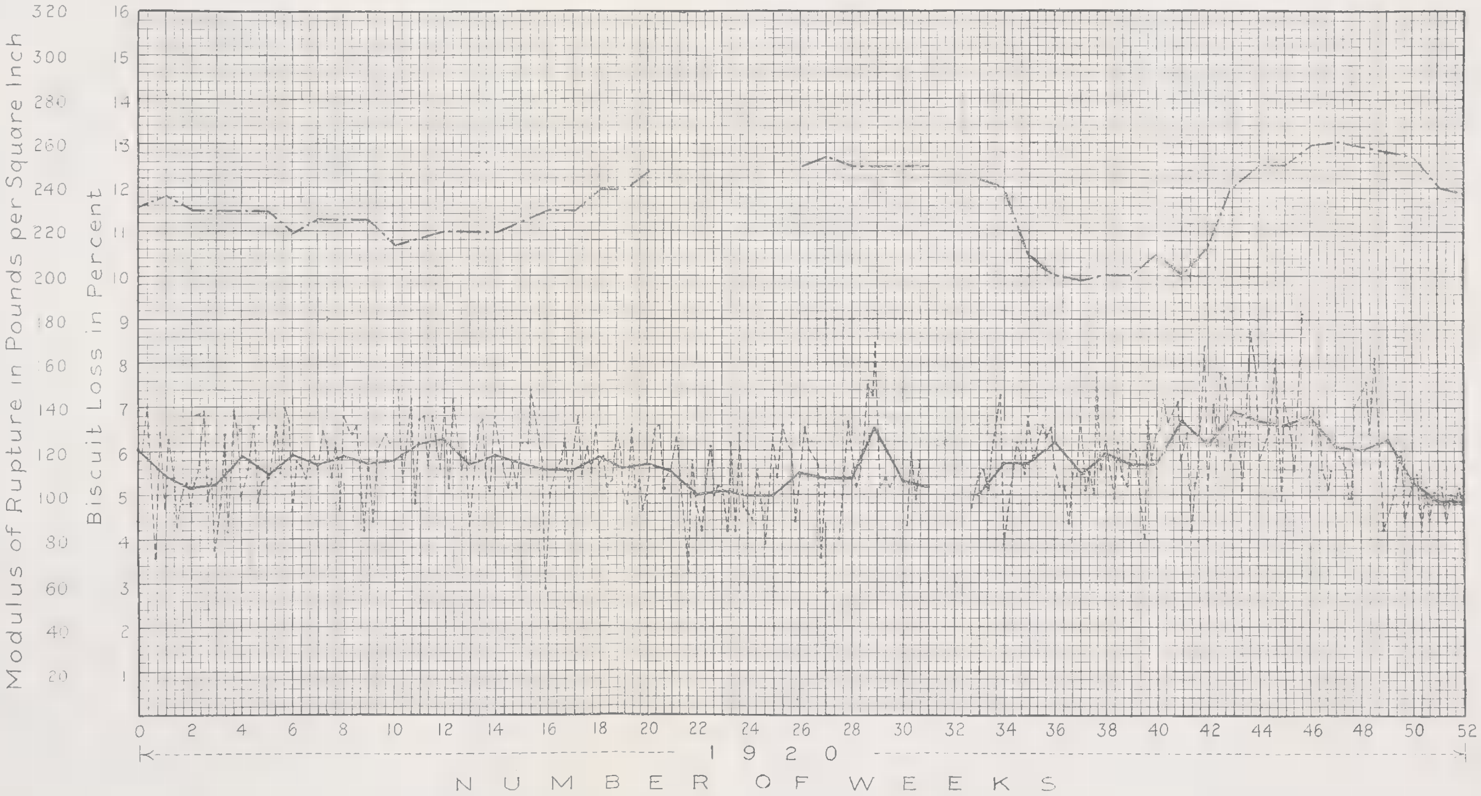
Nipped	0.438%
Warped	0.664
Rim cracked	0.742
Foot cracked	0.175
Bottom cracked	0.157
Dunted	0.704
Sympathetic dunts	0.620

Comparison of these normal percentages with the former set shows that by increasing the strength of the body in the clay the percentage of nipped and cracked ware is decreased but the percentage of warped ware is increased. The decrease in percentage of dunted ware was due to a decrease in the cooling time.

The purpose of the biscuit loss analysis is to determine as quickly as possible the cause of high losses which are common to all classes of ware,

BISCUIT LOSS – MODULUS OF RUPTURE CURVES
FOR
THE SEBRING POTTERY COMPANY'S BODY





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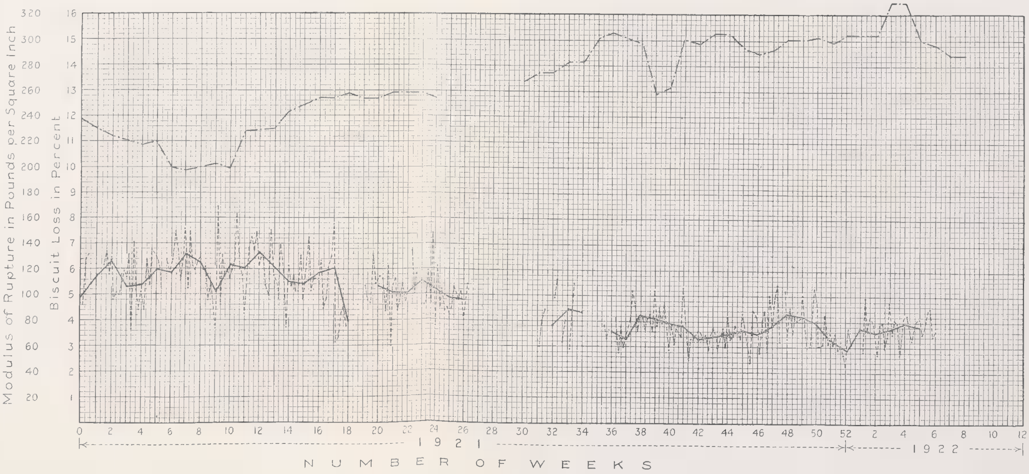

and apply the cure before they become chronic. This analysis will not take care of the special causes of damaged ware which may be local and found in one class of ware only.

Analysis of the Brushers Report.—In order to make the control of the biscuit losses complete there must be some means of watching the peaks in the daily losses, and decrease them before they become general. The brushers report is excellent for this purpose, but it is necessary to have the percentages of loss of each class of ware brushed figured and ready for study by 9 A. M. of the day following date of report. Unless the percentage of loss of all damaged ware is figured each day, it is useless as a guide for control.

All damaged ware sorted out one day should be ready for inspection on the following day. Then if a given class of ware shows an abnormal loss, the damaged ware is available for inspection and study.

Summary

The chief factor in the control of the biscuit losses is the transverse strength of the body in the clay state. If the modulus of rupture is maintained at 280 pounds per square inch the effect of careless handling of the ware is offset, and the Human Element automatically controlled. The effect of the Human Element is also made less effective by not taking the ware off of the molds until it is bone dry.

A daily analysis of the damaged seven inch plates will give early indications of such chronic troubles as, too weak a body, careless handling, improper firing, or too rapid cooling of the kilns.

Special losses such as edge cracks, cup handles coming off, etc., can best be detected and controlled from an analysis of the brushers report.

The writer acknowledges his indebtedness to Mr. C. L. Sebring for advice and assistance in this investigation.

Sebring Pottery Co.
Sebring, Ohio

NOTE ON THE EFFECT ON MANGANESE IN GLASS MELTED UNDER REDUCED PRESSURE[1]

By E. N. Bunting

The decolorizing action of manganese is destroyed by melting and fining glass at 1400°C under a pressure of 0.03 atmosphere. The decolorizing oxide, Mn_2O_3, is decomposed[2] under these conditions into MnO and O_2.

We have fined several small pots of glass in an electric furnace[3] in which the pressure can be gradually reduced. As the pressure is lowered, the dissolved gases bubble out, decomposable oxides dissociate, and the finished glass assumes the ordinary light green color, when cold, imparted by the FeO present. An interesting specimen was obtained in a melt in which the fining was incomplete, as the furnace winding burned out when the pressure reached 0.03 atm. The pot of glass turned out with the bottom 5 cm. colored light green, the 5 cm. mid-section colorless, and the top, about 2 cm. colored pink. The green section was free from bubbles, the colorless section contained many fine ones, and the pink top, more bubbles than glass. The glass contained 0.2% MnO and the manganese content of the three layers was the same.

The formation of the pink top layer was probably due to the high O_2 content of the gas in the bubbles, which before removal oxidized sufficient MnO to Mn_2O_3 to color the top glass pink.[4]

Ceramics Dept. U. of Ill.
Urbana, Ill.

Discussion

Mr. Hostetter:—Is there any discussion on this interesting experiment of melting glass in vacuo?

Mr. Wright:—I would like to ask Dr. Bunting if he has ever attempted to melt a glass containing selenium under reduced pressure?

Mr. Bunting:—No, we have not.

Mr. Wright:—Don't you think it is possible to obtain colorless glass, green glass, and pink colored glass when a tank is closed down if the glass contains selenium?

Mr. Hostetter:—Melted under ordinary conditions?

Mr. Wright:—Yes.

Note: No member had any definite views on this point.

Mr. Hostetter:—What is the effect, Dr. Bunting, of having arsenic in the glass?

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[1] Presented before the Glass Division, St. Louis Meeting, Feb. 28, 1922.

[2] K. Honda and T. Soné, *Sci. Repts. Tohoku Imp. Univ.*, **3**, 139–52.

[3] *Eng. Expr. Sta. Univ. of Ill., Bull.* No. **118**, 12.

[4] S. R. Scholes, *Jour. Ind. Eng. Chem.*, **7**, 1037 (1915).

MR. BUNTING:—All volatile constituents keep boiling out.

MR. HOSTETTER:—I suppose this effect is really a substitute for arsenic?

MR. BUNTING:—It is.

MR. FORSYTH:—Was this specimen made in connection with the measurement of the particular gas?

MR. BUNTING:—No. The object was to fine the glass at reduced pressure.

A MEMBER:—Was there any oxidizing agent added?

MR. BUNTING:—No.

A MEMBER:—Was there any nitre used in the glass?

MR. BUNTING:—We do not know how the glass was made. It was furnished by the General Electric Company. They furnished an analysis but no batch formula from which the glass was made.

MR. HOSTETTER:—Perhaps Mr. Forsyth will tell us whether nitre was used or not.

MR. FORSYTH:—The batch probably contained nitre.

MR. HOSTETTER: Was that a lime glass?

MR. BUNTING:—No. It was a light flint.

BY E. W. TILLOTSON:[1]—I should like to inquire whether the author determined the course of the light green color of the bottom layer of this sample. It has been repeatedly observed (S. R. Scholes, *Vide supra* and *Jour. Soc. Chem. Ind.* **35,** 518(1916); Frink, *Trans. Am. Ceram. Soc.* **19,** 370, (1917); Tillotson, *Ibid.*, **19,** 375, (1917)) that a green color may be produced in glass by manganese which perhaps in this case is in the form of manganate (MnO_3). At least this green manganate color may be seen in the partially fused batch the composition of which is favorable for the formation of manganates.

In view of this the following explanation of the observed phenomena is offered. (1) The bottom portion is colored green due to an excess of manganate (MnO_3). (2) In the middle portion a part of the green MnO_3 is dissociated to the complimentary pink Mn_2O_3 so as to produce a "colorless" glass. (3) In the top layer the dissociation has proceeded farther giving rise to an excess of Mn_2O_3 and a decided pink color. The bottom layer was free from bubbles indicating no disengagement of oxygen; the colorless region contained a few bubbles indicating that dissociation had commenced; and the top layer contained many bubbles indicating a large disengagement of oxygen.

REPLY by Mr. BUNTING:[2]—The explanation offered by Dr. Tillotson is probably incorrect for the following reasons:— (1) While the glass is being

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[1] Received June 30, 1922.

[2] Received August, 1922.

fined under the reduced pressure, the whole mass of glass is full of bubbles therefore it can not be said that there was no evolution of O_2 from the bottom layer. (2) Similar melts where the fining is more complete are wholly colored green. It seems to me very improbable that at a temperature of 1400°C *in vacuo* any MnO_3 would not have been reduced to MnO, as the dissociation temp. of MnO_3 is considerably below 1400°C.

REFRACTORIES FOR ZINC SMELTING[1]

By G. C. Stone

Introduction.—The refractories required in zinc smelting can be divided into five classes, depending upon the uses to which they are put: (1) Roasting Furnaces; (2) Oxide Furnaces; (3) Spelter Furnace Linings; (4) Retorts; (5) Condensers.

Roasting Furnaces.—Practically all of the roasting of zinc ore in this country is done in one of four types of furnace, the Ropp, or Cappeau, Zellweger, Spirlet, and Hegeler. The Ropp and Zellweger furnaces are largely used in the natural gas district of the Southwest. They are not hard on the refractories as the temperature is not high, there is very little corrosive action from the charge, and the traveling rakes are supported independently of the furnace bed. Under these conditions any reasonably good fire brick is satisfactory. The Spirlet furnaces have been used but little, and practically all of the brick used in them are special, and there is no published information regarding their requirements or performance. Probably the largest part of the roasting of zinc ores is done in Hegeler furnaces, and owing to their form a special trouble has developed with the refractories. These furnaces are very large, about 80 feet long, 17 feet wide, and 30 feet high. Everything is in two parallel sections. Starting from the bottom each section has regenerative chambers, and above, three gas chambers, seven roasting hearths and frequently special air passages. The arches from both set about on the center wall (Fig. 1). The life of the furnaces is long, as the temperatures are not excessive and there is but little corrosion or wear, but the load acting on the center wall, which is maintained at a relatively high temperature, causes it to settle badly. This settlement is very serious and is usually the cause of rebuilding of the furnace. It is not uncommon to find the inner side of the hearths five inches lower than the outer, which spoils the work, the ore tending to accumulate on the low side to such a depth as to retard its roasting and reduce the capacity of the furnace very materially. This irregularity is most noticeable crosswise of the furnace, but the middle is also lower than the ends, which causes irregularity in the movement of the ore. This excessive and irregular settling is apparently due to two causes. The irregularity is due mainly to the difference in temperature of the outside and center walls. The settling is mainly due to the shrinkage of the brick on account of their not having been burned long enough at a sufficiently high temperature. A contributing cause in many cases is the irregularity of the thickness of the bricks used, which necessitates heavier joints than are desirable, as the mortar shrinks more than the brick. It should be possible to burn brick so that even long-continued heating

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[1] Received June 27, 1922.

to a temperature of about 850°C (1560°F), and never exceeding 900°C (1650°F) would not cause a shrinkage of from one to three per cent.

Oxide Furnaces.—The refractories in furnaces making zinc oxide have to stand a fairly high but by no means excessive temperature, with sudden drops by air cooling when the furnaces are cleaned out and charged every six or eight hours. In addition, when the ores contain much lead there is very severe corrosion from the lead fumes, particularly in and around the openings in the arch through which the gases and vapors discharge. With good brick, well laid, a furnace working lead free ores should

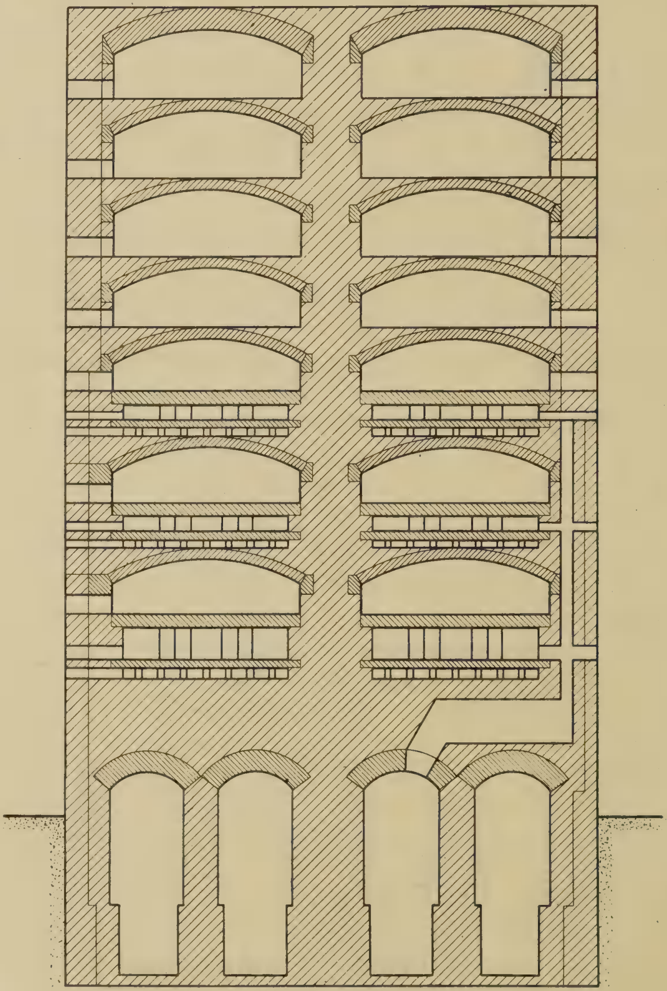

FIG. 1.

last from three to four years. With leaded ores the life is much shorter. Much depends on the design, and the life can be considerably increased by using properly designed special shapes. The temperatures are not excessive, about 1000°C (1400°F), but the frequent changes of temperature and rather severe handling in breaking up and removing the charge often damage the brick. We have found dense, hard-burned brick the best. In this case, as in most others, it is easier to get the necessary qualities in a brick that will not stand a much higher temperature than it is to be used at than in a more refractory one.

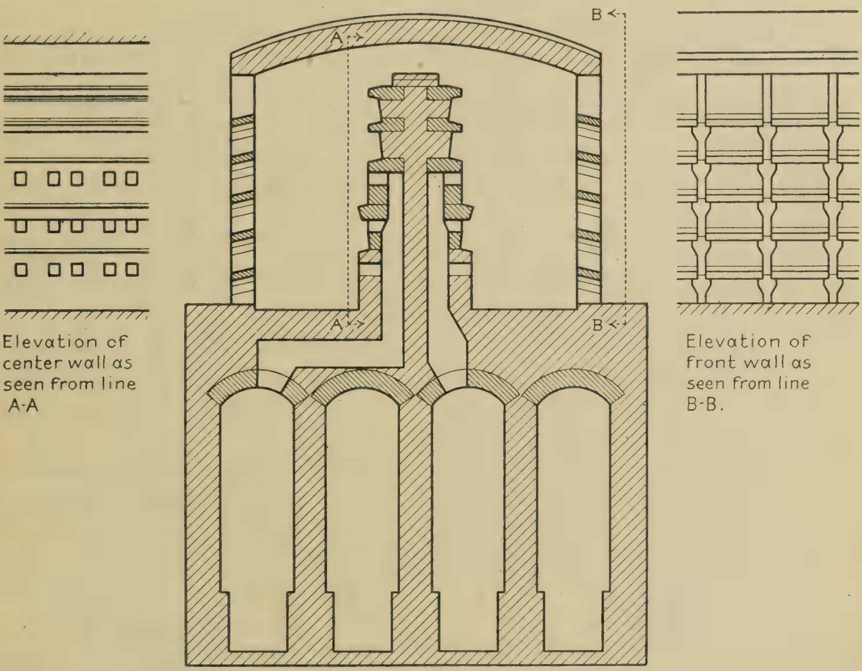
B
A
A
B
Elevation of center wall as seen from line A-A
Elevation of front wall as seen from line B-B.

Fig. 2.

Spelter Furnace Linings.—Spelter furnace linings have to stand a high temperature for long periods, with a regular daily variation between about 800° and 1400°C (1400° to 2500°F). When the furnace is being charged in the morning the gas is shut off, and the temperature drops to the lower limit; it is then gradually raised to the upper one, and kept there for about six hours. The furnace is then cleaned out and recharged. In addition to the high temperature more or less coal ash is carried in by the gas, and slag from broken retorts gets over the inside of the furnace. Owing to its peculiar functions, practically the whole of the lining is made of special bricks, many of which are very large (Fig. 2). These very large bricks are very difficult to dry without warping and cracking, unless they are either made very porous or dried very slowly. The former gives a poor block and the latter is expensive. In consequence we have not been able to buy nearly as good linings as we make. When tried under the same conditions, our own make of block lasts at least three times as long as the best we have been able to buy. Some of the lining blocks, notably those called plates, are subjected to relatively large transverse loads. In a properly designed furnace these can be replaced, but doing so is troublesome and causes an expensive loss of time. The brick walls give trouble from shrinkage, like the center walls of the roasting furnaces, but in regenerative furnaces this can be compensated for by making the back wall a little higher than it should be at the start, so that the shrinkage leaves it at about the proper height. What is required is a brick that will stand the temperature and be close grained, strong and sound.

Retorts.—The retorts are tubes with one end closed, and are from four to five feet long. The section is either circular, from seven to ten inches in diameter, or elliptical, from 6 x 9 to 8 x 15 inches. The walls are about one inch thick. They are nearly always made in hydraulic presses and immediately placed in the drying rooms, where they are kept until used. The general practice is to keep retorts for at least three months before burning. Most spelter men prefer to keep their retort longer than this when possible. The retorts are burned as required in small kilns, placed close to the furnaces, and are put in the latter while red hot. Under such conditions it is obvious that they must be made at the plants where they are to be used, and practically all of the smelters have learned how to make reasonably satisfactory retorts. Their life is from 30 to 40 days. The term life is apt to be misleading, as they are often discarded because they are filled up with slag and not because they have given out.

Retorts should be capable of standing a temperature of 1600°C (2900°F) without deflecting materially when supported only at the ends, with a clear span of about four feet. They must be dense, so as to be impervious to gases and zinc vapor. Porosity, if caused by enclosed spaces that do not communicate with each other is not as detrimental as fine cracks running through the walls. The material from which the retorts are made must not be easily attacked at the furnace temperatures by the impurities in the ore worked, or by zinc vapor. The last condition, susceptibility to attack by zinc, has not been studied to any extent, but is important as old retorts are always colored purple by this reaction and are brittle. Thin sections of such retorts show crystals of spinel which have been formed.

The reaction by which the spinel is formed is rather obscure and has not been much studied. The reacting bodies are silicate of alumina

metallic zinc as vapor, and in addition there must be oxygen. It appears to me that the latter is supplied by the dioxide of titanium, TiO_2, in the clay, and that the reaction probably is as follows:
$Al_2O_3, \ 3SiO_2 + Zn + 2TiO_2 = ZnO, \ Al_2O_3 + 3SiO_2 + Ti_2O_3$.

Both zinc spinel and titanium sesqui-oxide are purple. The volume of the products calculated from their gravities is greater than that of the reacting bodies, which would account for the slight swelling and marked weakening caused by the reaction. A careful study of the conditions effecting the production of zinc spinel would, I believe, be of value.

Condensers.—Condensers are also always made by the smelters, but there is no reason that they should not be made by the manufacturers of refractories. They are usually clay cones, 16 to 20 inches long, about two inches in diameter inside, at the small end, and six at the large, with walls about $^5/_8$ of an inch thick. They are not subjected to a high temperature, not over 600°C, (1100°F) but they get rather rough handling as they are taken down and scraped out each morning. They should be impervious to zinc and zinc vapor and strong enough to stand rough handling. The cost of condensers is a relatively small part of the smelting cost, and there is a much greater difference in their quality than in that of the retorts.

General.—The refractories used in zinc smelting should be able to stand the temperatures to which they are to be subjected, and these temperatures are known, so that they can be specified for the particular cases.

All refractories should be as dense and strong as possible. This not only minimizes the attack by slags, but makes them impervious to zinc vapor, which is a frequent cause of damage.

They should be true to shape and dimensions. In most cases exactness in length and width is not as important as uniformity in thickness, as it is obvious that if the brick in a course vary much in thickness the joints will necessarily be thicker than they should be, and will either shrink and open up, allowing attack by slag and gases, or the walls will settle and cause trouble. For the same reason the top and bottom surfaces must be flat.

The troubles with refractories are not all due to the latter. Many furnaces in use are badly designed, and changes in the shapes and positions of the blocks would increase their life in many cases. The brick are often blamed for defects when the short life is due to poor brick laying and not to poor brick. From my own observation I should say that less than 5% of the brick used are laid in a manner calculated to give the best results, and fully half are very badly laid.

New Jersey Zinc Co
New York City

PRELIMINARY REPORT OF THE COMMITTEE[1] ON FUEL CONSERVATION ON THE RAILROAD TUNNEL KILN

The program adopted by this Committee covered two investigations considered most important to the members of The Refractories Manufacturers Association with reference to the conservation of fuel. The first of these investigations had for its object the determination of the ability to reduce fuel consumption with the present kiln equipment and the second, the determination of the value of the railroad tunnel kiln to this particular industry. This report will deal with the tunnel kiln.

The industry, we believe, realizes the fact that manufacturing costs must be reduced and, as the cost of burning the ware is one of the largest items entering into cost, it will be realized that any reduction in this item would be decidedly advantageous.

The ceramic industry has for many years wasted far more fuel than any industry in the country. Any method or apparatus, therefore, that could be developed to make the firing of ceramic wares more efficient should be a very welcome thing, not only to the industry but to the country at large.

It should be explained that in the firing of ceramic ware in periodic kilns the greatest fuel losses are in the heat carried out of the kiln in the highly heated combustion gases; the heat radiated from the exterior of poorly insulated side walls and crown arch and the heat left in the ware and kiln structure at the end of the burn. The average losses, as calculated from carefully conducted tests, are shown below:

Heat taken up by ware..........................	12%
Heat lost in combustion gases......................	25%
Heat lost in ashes................................	4%
Heat taken up by kiln and lost by radiation........	59%

If the necessary means were employed, a large part of the first expenditure could be reclaimed. A regenerative or recuperative provision would greatly reduce the second loss, while a thorough heat insulation of the structure would reduce the radiation loss materially.

Part I

The Continuous Car or Railroad Tunnel Kiln

With the idea of reducing the heavy heat losses noted, there has developed a kiln structure, known generally as the "Continuous Car Tunnel Kiln," or the "Railroad Tunnel Kiln." With the use of this type of kiln, the fuel consumption is only from 15 to 30 per cent of the average periodic kiln requirement and, therefore, other things being equal, the tunnel kiln is going to take a very prominent part in the future firing of ceramic wares.

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[1] Refractories Manufacturers Association.

In this type of kiln the ware is mounted on iron or steel cars having refractory platforms. The entire length of the kiln is filled at all times with a train of these cars, which keeps moving almost continuously from the charging end toward the discharging end. A series of furnaces are provided on each side of the kiln approximately midway of its length and the combustion gases from these furnaces pass immediately into the tunnel proper and come into direct contact with the ware setting. These gases then proceed toward the draft ports near the charging end of the kiln—traveling in a direction opposite to the movement of the cars. Fresh air from the pressure fan is introduced through a blast head just underneath the kiln crown at the discharging end. This air, which is introduced largely for cooling purposes, takes the heat from the fired ware and upon reaching the furnace section of the kiln functions as secondary air for combustion—mingling with the combustion gases from the furnaces and proceeding with these gases to the draft ports. From this it will be seen that if the kiln has sufficient length, the combustion gases will leave the kiln at a relatively low temperature. Furthermore, the ware leaving the kiln will have given up most of its heat to the incoming fresh air. The only other heat loss of any consequence is radiation, which is probably taken care of in a better manner than is done on any other kind of ceramic kiln, *i. e.*, at the center or high temperature section of the kiln, where the walls and crown have heavy insulation; the intermediate portions are insulated to a lesser degree and the ends are only slightly insulated.

History

This kiln originated in Europe—the first one appearing at Vincennes, France in 1751, and was used for firing overglaze colors. The first kiln of this type proposed for firing brick was covered by a Danish patent in 1840. This was followed by a kiln which was described in a German publication in 1848, and consisted of merely the heating end and the combustion compartment, but no cooling end. When the ware had passed through the high temperature zone it was removed and placed in another tunnel, or compartment, to cool. Other designs embodying various ideas of construction were then brought out, some of them not differing greatly from the modern kiln.

In 1877, Otto Bock was granted a German patent and he built about sixty of these kilns—most of them proving failures. Within the last fifteen years or so more successful kilns have been developed, particularly the kiln of the Faugeron or, as it is known in this country, the Didier-March type; a number of these are now in successful operation in Europe and America.

The American history of this type of kiln seems to start with a kiln erected in Chicago about 1889 by J. C. Anderson for the firing of dry-press brick. Mr. Anderson took out two patents about this time, both pertaining to the twin-tunnel type. He soon built another kiln at Long Island City, but neither kiln operated for any great length of time. In 1910 two kilns of the Faugeron type were built at Keasbey, N. J., and as these kilns are still in operation, it can probably be said that they were the first successful kilns built in this country. About the same time several kilns of this type were built by Mrs. Shaw, one of them at Atlanta and another at Savannah, both of them proving absolute failures. The muffle type of kiln was introduced to this country from England about 1915 and has been attended with considerable success, particularly in the burning of white wares. Other kilns have been brought out from time to time—some admitted failures and others with varying degrees of success.

A large number of patents have been issued in this country on tunnel kilns which have never been built. Up to the middle of 1919, the records of the United States Patent Office indicated that at that time there were in force sixty-three patents relating to tunnel kilns and about as many more which had expired.

At the present time the available records would indicate that the following list covers the kilns erected and in more or less successful operation:

Direct-Fired Type:		
	Harrop Kiln	8
	Owens Kiln	13
	Russell (Zwermann) Kiln	5
	Didier-March (Faugeron) Kiln	7
Muffle Type:		
	Dressler Kiln	21
Miscellaneous:		
	Private Designs	7

Modern Development

In order that a better understanding may be had of the design, construction and operation of one of these kilns, the following description is given. This description covers a kiln of the direct-fired type which will not be named in this preliminary report. It is, however, a new and successful kiln and can be accepted as typical.

The kiln is used for firing a general line of low tension electrical insulators of both white and brown color. It is of the direct-fired type, and is equipped for using either natural gas or fuel oil or both together. The kiln proper is 4 ft. 6½ in. wide by 321 ft. long and holds fifty-two cars at one time. The setting of ware on each car occupies a space 4 ft. 2½ in. wide by 5 ft. 1 in. high by 5 ft. 9 in. long. A car is charged every hour and the train moves at the rate of 1.2 in. per minute. At the present time, four furnaces out of eight are being fired. With this manner of handling, the ware is under fire for thirty hours; the cooling period is twenty-two hours.

Periodic kilns are usually either up- or down-draft. The tunnel kiln is essentially a horizontal-draft kiln. It is a well-known fact in physics that hot gases tend to rise, and if hot gases are introduced into a room or compartment of any kind, these gases will promptly rise and flow laterally in the upper portions of such compartment. In the case of the tunnel kiln the hot gases tend to rise and flow underneath the crown toward the draft ports near the charging end. The usual result of this is that the upper part of the ware setting is subjected to greater heat work than the lower part, which is very evident from the quality of the ware discharged. Recognizing these facts, there has been provided in this kiln structure obstructions to the free flow of gases underneath the crown and also, the side walls are so battered as to give greater clearance for the flow of gases at the lower levels than near the top. Furthermore, the ware, or the placing of saggers (clay boxes) carrying the ware, is stilted up off the car platform, which permits a circulation of hot gases underneath the ware. The result of this arrangement is that with the greater amount of circulation taking place at the lower levels, a uniformity of temperature is secured over the entire cross-section of the ware.

Firing losses (cull ware) in this design of kiln are practically eliminated, as all ware passes through the kiln at a uniform rate and all of it encounters uniform conditions of heating rate, maximum temperature and cooling rate.

Cars

The car frame is a single gray iron casting with a gridded top and with two double-flanged wheels and two flat-faced wheels—both kinds being 12 inches in diameter. These wheels are equipped with caged roller bearings and each revolves on an individual axle.

On each side of the car is attached a depending steel plate, $^3/_{16}$ inch thick, which runs in the sand-seal trough on each side of the kiln tunnel.

On top of the car frame is laid a No. 14 gauge steel plate, which supports a 2½ in. layer of Sil-O-Cel (pulverized kieselguhr) and Portland cement (4:1 by volume).

The car is then covered with specially shaped fire-clay slabs, 9 in. thick—the top surface being the finished platform.

Car Pusher

The hydraulic ram which is used to propel the train of cars through the kiln was designed by P. W. Ott and is far more simple and inexpensive than the hand-operated or mechanical device in general use.

This ram carries its oil for actuating in a reservoir in its own base. A single plunger oil pump, driven by a back-geared one-half horse-power variable speed electric motor is employed. The plunger has a stroke several inches longer than the car and returns automatically at the end of its stroke, through the operation of a trip and a special three-way valve.

This pusher operates under a pressure of 600 pounds per square inch and the total pressure necessary to move the train of cars is approximately 8,000 pounds.

Kiln Construction

Carrying the entire structure is a well reinforced concrete foundation 18 in. thick under the side walls. The outer masonry walls are preferably of soft burned porous common brick laid in cement-clay-sand mortar. The lining of the tunnel (arch and sides) and the furnaces are of the highest grade fire brick carefully laid in a minimum amount of fire-clay mortar. Between the lining and the outer wall is heat insulating material which will be spoken of later. Special fire-clay shapes are used wherever necessary, which results in a more solid structure and at the same time saves a considerable amount of the mason's time, which would otherwise be used in chipping and fitting.

A sand-seal trough is provided in each side of the tunnel—the outer confining wall of which is a $^1/_4$ in. by 8 in. steel plate, extending the full length of the kiln. These sand troughs, in connection with the sand-seal plates attached to both sides of the cars, provide an effectual air-seal between the tunnel proper (in which the firing takes place) and that portion of the tunnel beneath the car platforms. This seal is necessary, as it is quite essential that the hot gases from above are not drawn underneath the cars, to injure the running gear; and it is equally important that the draft in the tunnel proper does not draw cool air from beneath, to chill the lower portions of the ware.

Longitudinal slots are provided in the side walls, in which the car platform fits rather loosely. The purpose of this is to intercept radiated heat, which would otherwise travel from the highly heated tunnel proper down onto the metal car frames and sand-seals. Any number of furnaces may be provided on each side of the kiln, depending upon the length of the high-temperature (or soaking) zone required for the particular ware. In all cases these furnaces have hollow walls. Air is circulated through these walls and then led to the burners or through the grates as preheated primary air for combustion.

Air is also forced through a low, wide flue over the arch of the entire cooling end of the kiln. This air is then led down over the furnace arches and finally delivered into the front of the furnaces as secondary air for combustion.

The furnace throat or connection between the furnaces and the tunnel is the full width of the furnace and in height extends from about 6 in. above the car platform to a point about three-fourths of the way up to the spring line of the tunnel arch.

The charging end is closed by a Kinnear rolling steel door, having a hole in its lower part through which the push rod is inserted for moving the cars. After the train has been moved one car length, and the ram returned automatically to the starting position, the rolling door is raised and a car of ware is pushed into the empty space in the kiln. The door is then dropped, the push rod put into place and the pusher started.

Steel angles 5 in. x 3 in. x $^3/_8$ in. running the full length of the kiln, are provided on each side to take the thrust of the kiln arch. Vertical buckstays of 6-in. I-beams are spaced at approximately 6-ft. intervals along the sides of the kiln, being anchored at their lower ends in steel U-straps cast into the concrete foundation and held together at their upper ends with $^3/_4$ in. diameter tie rods passing through unfinished gray iron castings slipped over the tops of the I-beams.

The side walls are provided with small peep holes, having iron frames and covers, to allow an inspection of the interior of the kiln and ware while under fire, as well as of the pyrometric cones used in determining the real heat work being done in the kiln. These holes are also used for taking pressure and draft readings, as well as gas samples for analysis.

Insulation

As radiation is one of the large losses in periodic kilns, special care has been taken in this kiln to reduce this to a minimum.

The best non-conductor of heat at high temperatures that has been developed is kieselguhr (infusorial or diatomaceous earth). This is readily available now in its natural state under the trademarked name of Sil-O-Cel and can be gotten either in the form and size of standard fire brick or as powder. One inch in thickness of this material is equivalent in insulating value to 12 inches of ordinary fire-brick masonry. This material may be used in the walls in the form of brick or block, or as a powder. Powder is probably preferable, as it leaves no large voids or air spaces between the common brick wall and the fire-brick lining.

In the furnace or high temperature zone, the side walls have 4½ inches of heat insulating material. The arch in this zone is also covered with the same amount of insulation.

Toward the ends of the kiln the insulation is reduced to 2½ in. in thickness and at the extreme ends no special insulation is employed.

Expansion

Expansion of a masonry structure, due to the raising of the interior to high temperatures, is a very difficult thing to handle. The expansion and contraction of a periodic kiln are very hard on the structure. It can be readily appreciated, therefore, what a serious problem expansion is in a structure over 300 ft. long.

In this kiln, expansion joints are provided about every 50 ft. in the foundation, in the side walls and in the tunnel arch, the several joints not being permitted to fall in the same vertical plane. The expansion joints in the side walls are "ship-lapped."

In every fifth mortar joint of the common brick side walls are placed $^1/_{16}$ in. x 1 in. steel strips, so that when it becomes necessary to close down the kiln, the several sections of the kiln wall will contract as monoliths, rather than develop unsightly diagonal cracks.

The track rails have mitered, spaced joints and slotted bolt holes to take care of the expansion in these members.

Firing Equipment

Only four of the eight furnaces are being used in the kiln at this time, these being fired with natural gas.

A No. 3 Maxon Premix burner is installed in front of each furnace. These burners consist of a small centrifugal blower operated by a direct-connected one-half horsepower motor. Gas and preheated air are drawn into the blower, which thoroughly mixes the two and then delivers the mixture at a high velocity into the furnaces. About 90,000 cu. ft. of gas are consumed per 24 hours.

Equipment is also installed for the firing of fuel oil during periods of gas shortage. The low pressure system is used—the Maxon blowers supplying the air. The Viking rotary oil pump, operated by a direct-connected one-fourth horsepower motor, is used to supply the oil pressure. This pump has a capacity of 2½ gallons of oil per minute, delivered at 35 pounds pressure through a $^3/_8$ in. diameter pipe to the oil heater. The oil pumping and straining equipment is in duplicate, so that continuous operation may be assured.

Power

The draft fan is a centrifugal steel plate exhauster. The wheel is "overhung" and the shaft is provided with water-cooled bearings. A 10 horsepower motor is provided for this fan.

The centrifugal steel plate pressure fan, which supplies the air for cooling and for combustion, is operated by a 7½ horsepower belted motor.

Aside from the firing equipment, the total power actually required to operate the kiln is probably not in excess of 12 horsepower.

Pyrometric Installation

Electric thermocouples are inserted into the tunnel through the center of the arch—noble metal couples being used in the high temperature parts and base metal couples in those parts where the temperature does not exceed 1500°F. The cold end junctions of all thermocouples are buried in Sil-O-Cel in 12-in. square boxes, so as to prevent fluctuations in the pyrometer readings.

All pyrometer wiring is carried in conduits.

The instruments used are the wall type of indicating galvanometer and the recording galvanometer. The former is used in securing the temperatures for the gradient records and the recorder is used for checking up temperatures during the night and on holidays, to see whether the firemen have been watchful or not. It furthermore enables the firemen on the different shifts to compete with each other in securing constant temperatures during their tricks, which is indicated by a straight, non-waving line.

Part II

The Committee has so far had the opportunity of visiting six plants operating railroad tunnel kilns and intends visiting two others before presenting its final report. A short description of the kilns visited follows.

Dressler Kiln
Champion Porcelain Co.

The operation of this kiln is extremely interesting on account of the fact that it is the only one in the country, so far as known, that is operating at from cones 18 to 20 down. In the first place it demonstrates that the highest temperatures required in this industry can be and are reached in this type of kiln.

The installation is, without a doubt, the best and most complete in the country and no item of expense has been spared that would make for perfect operation and results. The kiln is burning spark plug porcelains having a composition approaching that of Sillimanite; the ware is enclosed in saggers or refractory boxes.

The kiln is 305 ft. long and is fired with city gas. It holds 48 cars and ordinarily operates on a one hour basis, *i. e.*, one car is put into the kiln and one taken out every hour, making the total elapsed time a car is in the kiln, forty-eight hours. At the time of the visit of the Committee it was operating on a 1½ hour schedule.

Unlike other kilns this is the only one in the country which is operating without a sand-seal for the protection of the iron work on the cars. This kiln is equipped with a system of water cooling pipes traversing its entire length and extending from the rails to the top of the iron work on the cars.

The cars are of cast iron, equipped with roller-bearing trucks and can be pushed by one man when loaded with ware. They are lubricated with 600 W oil.

The kiln is equipped with a hydraulic ram for moving the cars through the tunnel and is also equipped with automatic control buttons which stop the cars should the pusher fail to stop its pushing action when the proper point has been reached.

On a 1½ hour schedule the products of combustion leave the kiln at between 480° and 550°F. This is lowered somewhat when the cars are traveling on a 1 hour schedule.

As this is a muffle kiln, none of the products of combustion come in contact with the ware and the atmospheric conditions inside of the kiln are under absolute control, either oxidizing or reducing conditions being maintained at the will of the operator.

This kiln being the first one to operate at high temperatures has been experimental so far as the refractory lining of the high heat zone is concerned. It has been down twice at six month intervals for repairs to the lining in this zone. The muffles are made of carborundum and it appears that this is the only refractory that will give satisfaction, although there is still a question as to whether the proper mix has been worked out. Originally the section of the crown covering the high heat zone was constructed of silica brick, all other sections being of No. 1 Missouri fire brick. After six months' operation, the silica section was found to be in perfect condition, while the sections adjoining at each end had settled to such an extent that it was found necessary to replace them. The replacement was made with silica brick and, after a further six months operation, they were found to be in perfect condition. This would seem to indicate that silica brick should be used in these kilns whenever possible where high temperatures are obtained.

As an indication of the up-keep cost of the muffle type kiln at the temperatures obtained, it is interesting to note that the refractory repairs have averaged, to date, from $700 to $1000 per month. In this connection it should be borne in mind that this kiln is the pioneer in high temperature work and that, as a result of the lessons learned, it can not be questioned that on future kilns the depreciation would be considerably reduced.

It is interesting to note that this company has already started construction on a Harrop kiln of the direct-fired type in which the same temperatures will be obtained. After a thorough investigation, the officials of the company are of the opinion that this kiln can be built for less than one-half the cost of the Dressler kiln; that their results will be equal and that the up-keep cost will be reduced to practically nothing. This kiln originally cost over $100,000. It was built during the period of peak prices.

Champion or Balz Kiln
Champion Ignition Co. While this kiln can not be used for the burning of refractories of the ordinary type, it is, nevertheless, interesting as a development of an entirely new principle which is bound to find its place in the ceramic industry.

There are two kilns at this plant, only one of which has been operating. This kiln was originally 60 ft. long, but there has since been added an additional 15 ft. on the cooling end. This addition, however, has a sheet iron roof and is really only a cooling compartment. The kiln is divided into three zones,—20 ft. to the heating-up zone, 20 ft. to the high fire zone and 20 ft. to the cooling zone. The tunnel is only 36 in. high and 32 in. wide. The cars have decks 48 in. long by 24 in. wide and are 15½ in. high.

The kiln is fired with city gas on the surface combustion principle, there being five burners on each side, the flame being directed toward the crown (which is composed of carborundum brick) and reflected on to the ware, which is set on open fire-clay trays.

These trays are stilted above the fire-clay decks of the cars by means of fire-clay blocks, the trays containing spark plug porcelains which finish at cone 16–17. Beneath the trays are burned glazed tile of the Faience type which finish at cone 3. As the trays are only about 1½ in. thick an idea of the difference in temperature between the upper surface which reaches approximately cone 16 and the lower surface which reaches approximately cone 3, can be gotten.

The kiln is equipped with a sand-seal and the cars are placed in it on a 48-minute schedule, the ware being completely finished in 12 hours. The cars move at a rate of one foot in twelve minutes, being operated by chain drag.

This company originally used down-draft potters kilns, burning coal. Their burning time has been reduced from four to five days to twelve hours, but there has been no saving of fuel cost on account of the substitution of city gas, at about 70c per thousand, for the old method of coal firing. The losses have been reduced, however, from 10 to 12% to 6 to 8%.

The new kiln at this plant embodies some new ideas which may be valuable in other types of tunnel kilns. The principal one of these is the construction of the kiln walls and crown on concrete piers supporting reinforced concrete beams. This leaves a clear space between the piers from the floor line to the height of the sand-seal and thereby gives complete circulation beneath the cars which will naturally keep the temperature of the iron car approximately that of the kiln shed. This kiln is 87 ft. long, 36 in. high, and 5 ft. wide, the cars having decks 5 ft. x 5 ft. 3 in. In this kiln the heating-up, burning and cooling zones are of equal length, but the cooling zone is built almost entirely of sheet steel sections of very much the same type of design as the Proctor dryer. Water cooling pipes have been installed for almost the entire length of the cooling zone to expedite the cooling ware. The cars are moved by means of a chain drag.

Russel (Zwermann) Kiln
Kalamazoo Sanitary Mfg. Co.

This company is operating two kilns which were the original ones built under the direction of Zwermann. They are of the single funnel type and not the twin-type which he subsequently developed. These kilns are 360 ft.

long, although they were originally shorter. One of them is burning closets and tanks to cone 10 and the other is glazing the bisque bodies at cone 6.

The tunnels are 7 ft. 6 in. high to spring of arch, the arches having a 15 in. rise. The kilns are 76 in. wide. The cars are 7 ft. 6 in. long, 5 ft. 9 in. wide and $2^1/_2$ ft. high to top of deck. They weigh $6^1/_2$ tons when loaded and are 32″ gauge. On account of their great weight, winches are required to move the cars about the plant. It is estimated that these cars would hold 3,000 9-in. fire brick.

Each tunnel holds 48 cars, which move at the rate of a car length in $1^3/_4$ hours in the bisque kiln, and 2 hours in the glost kiln.

Each kiln is equipped with five oil burners, which are staggered three on one side and two on the other. Tate-Jones and Stakleen burners are used with an air pressure of thirty pounds and an oil pressure of twenty pounds per square inch. The high fire zone is in the exact middle of the kilns.

The kilns are equipped with sand-seals and the bottoms of the cars are air cooled. They are equipped with fan-draft and the temperature of the exit gases at the cooling end are approximately 130°F. The temperature of the ware coming from the kiln is approximately 350°F. Although the ware burned has a thoroughly vitreous porcelain body, it is not damaged by this exit temperature.

Cooling is expedited in this kiln through the use of false walls and crown, the cooling end being a double tunnel. Air is drawn through this space by means of a fan and distributed through heating pipes to the dryers and various parts of the building for heating and drying purposes. The temperature of this air is about 250°F. These kilns are equipped with two small auxiliary chimneys about 8 in. in diameter which extend through the crown in the high heat zone. Each is provided with a damper. The function of these stacks is to make it possible to draw any reducing gases which may form eddies in the burning zone. They serve to keep the kiln atmosphere thoroughly oxidizing.

The up-keep on these kilns has been remarkably low. They have been operating for five years and during that time have been shut down but three times, one of these occasions being when the factory burned down. Neither of them have been shut down during the past three and a half years and at the present time are in perfect condition. There has been absolutely no repairs to the refractory linings since they were originally constructed. The high heat zones are lined with a Missouri fire brick which has a fusion point of cone 32–33.

One of the points worth noting in the operation of these kilns is that the ware, which is placed in saggers, is set on each end of the car with an open space in the middle extending from top to bottom. The length of the cars is such that this open space is directly opposite the oil burners, the space therefore being really a combustion chamber. It was found necessary to leave this space in order to prevent the oil from being impinged on the saggers, it being found that if allowed to do so, a sort of rotting effect took place. This effect, however, would only be encountered where oil fuel was used.

The variation in temperature from top to bottom of these kilns is less than one-half cone, there being no variation from side to side.

The loss in the bisque kiln is about $2\frac{1}{2}\%$ as against 8 in the periodic and 2% in the glost kiln as against 8 in the periodic. Again in this case, there has been no particular fuel saving due to the fact that fuel oil was substituted for coal.

Farber Kiln
Farber Fire Brick Co. The kiln at this plant was designed by themselves, being patterned after the Didier-March kilns at Keasbey. No exact construction details will be given as it was requested that this be not done. The kiln is approximately 250 ft. long and the cars contain from 2,000 to 2,500 9-in. brick. The product is entirely dry-pressed, the semiflint fire clay of the Mexico district being used. The ware is taken directly from the presses and set on the kiln cars. The cars are then taken into a drying room, where most of the moisture is driven off; they are then placed directly in the kiln. This kiln produces from 10,000 to 14,000 9-in. brick per day and is operated by producer gas.

The brick are burned under oxidizing conditions and come from the kiln almost a paper white. The clay used contains nodular pyrites, some nodules being quite large, but under the burning conditions these do not ordinarily make bad iron spots.

In this kiln were embodied a number of original ideas which have not worked out as successfully as was hoped for but in spite of this fact the results have been satisfactory to the operators. The product coming from this kiln is practically 100% salable and is an active competitor with other brands of equal grade in the Mexico district. The product is shipped as far east as Cleveland and Detroit, where it comes into active competition with Kentucky and Pennsylvania brands.

It was noted that the bottom brick were often kiln marked or cracked, due to the superimposed weight which is to be expected where a dry-press product is set direct from the press to a car which gets considerable moving before reaching the burning zone.

The operation of this kiln, especially under these conditions, proves beyond a doubt the feasibility of burning the clays of the Missouri district successfully in this type of kiln.

Harrop Kiln
Mt. Clemens Pottery Co. At this plant are two Harrop kilns, one bisque and one glost. The bisque kiln will be described.

This kiln is 323 ft. long and 4 ft. $6^{1}/_{2}$ in. wide and is operated on a $1^{1}/_{2}$ hour schedule to cone 10. It was erected about eight months ago and has been operating continuously except for one shut-down caused by labor trouble.

The ware produced is table china. While this kiln is at the present time operating on a $1^{1}/_{2}$ hour schedule, it has been shown capable of a much greater capacity and has given satisfactory results on a fifty-five minute schedule.

The kiln is fired by means of six coal-furnaces which are located three on each side of the center in a staggered position. The furnaces are equipped with stokers and preheated air is supplied for primary and secondary combustion. This air is blown through channels in the walls and crown of the cooling zone by means of a fan and is fed to the fire boxes at about 400°F.

The combustion gases are exhausted at 400°F and the ware is taken out at a temperature of 650°F. At the present time a fan is being installed for the purpose of reducing the temperatures of the exhaust gases and the ware at the exit.

Cars used are single gray iron castings with a gridded top and having two double-flanged wheels on one side and two flat faced wheels on the other. This arrangement takes care of any expansion or contraction in the track gauge.

The kiln holds 48 cars and the cars are moved by means of a hydraulic ram which carries its oil for actuating in its own base.

The kiln has a sand-seal and the cars are effectually air-cooled as is shown by the fact that they are easily pushed by one man and are lubricated with 600 W oil.

This kiln, which, as stated before, is operating at cone 10, is lined through out the hot zone with dry-pressed Missouri fire brick which, up to date are apparently standing up perfectly.

This kiln offers a splendid opportunity to judge as to fuel saving. The company formerly operated down-draft pottery kilns, coal fired. With its present installation, also using coal, they show a fuel saving ranging from 75 to 85%. They have had no kiln repairs to date and feel certain there will practically be none; they claim no labor saving although it is self evident that there must be some.

This kiln cost $60,000 and was built in 1920 at the time of peak prices. It is estimated that it could be duplicated today for $50,000.

Didier-March Kiln
Didier-March Company This kiln was built in 1910 and has been in almost continuous operation since that time. It is 197 ft. long with the high heat zone somewhat nearer the coiling end

than the heating-up end. It has been used entirely for the burning of refractories.

The kiln holds 36 cars which are operated by a chain drag at the entering end. Each car holds from 920 to 1,000 9-in. brick. The kiln is operated ordinarily on a 2-hour schedule at from cone 10 to 14 and has a capacity of approximately 14,000 9-in. equivalent per day. Each car remains in the kiln from 60 to 72 hours.

The kiln is equipped with a sand-seal and the cars are air-cooled.

The kiln is fired with Youghiogheny coal, the average fuel consumption being from 650 pounds to 700 pounds per thousand 9-in. brick, which represents a saving of over 60%, based on the consumption of the round down-draft at the same plant. Taking into consideration setting, burning and emptying charges, the saving is in excess of 50%.

The temperature of the combustion gases at the exit is approximately 300°F. This could undoubtedly be reduced were the kiln not so short.

Primary air for combustion is delivered to the fire boxes in a preheated condition, this air being drawn through the cooling ware.

The breakage in this kiln has averaged less than 1%. The up-keep has been extremely small, the main parts of the lining being part of the original installation. This lining was of high grade fire brick, presumably of New Jersey manufacture.

As the operation of this kiln was dealt with in detail by Mr. Raymond M. Howe in his report[1] of September 19, 1917, it is considered unnecessary to go into further detail.

Part III

Tests on Firebrick

The Committee came to the conclusion that, as Mr. Howe had spent so much time in making physical tests on various brands of fire-clay brick for the purpose of the report above referred to, it would be unnecessary and merely a repetition to make further tests of the same character. It must be borne in mind that Mr. Howe's tests were made on a kiln that is shorter by at least 100 ft. than would be recommended for the burning of refractories by any present day tunnel kiln engineer. It must also be remembered that any tests carried on would have to be made under the conditions prevailing in the kiln selected and that while these conditions might be correct for one or half a dozen clays, they could hardly be correct for all the clays selected for a test.

In order to make this report more complete, the findings of Mr. Howe's investigation are included herewith.

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[1] Howe, *Special Report,* Refactories Manufacturers Association's Industrial Fellowship. No. 1. "A Study of the Tunnel Kiln and Its Application to the Burning of Refractories."

Discussion of Physical Tests

I. These brick were made by the stiff mud process using an auger machine, and were steam repressed. New Jersey fire clay, grog and ganister were used in the batch. The ware burned in the tunnel kiln showed the same physical properties as the ware from the intermittent kilns. The slight difference observed was more likely due to experimental error rather than conditions of burning.

II. These brick were made by the soft mud process from 15 per cent bond clay and 85 per cent flint clay, part of which had been calcined. The clays were from the Cambria district. The ware coming from the tunnel showed greater shrinkage, greater strength, and lower porosity, all of which indicated that the tunnel kiln burn was more thorough.

III. These brick were much the same as those of type B—being higher in flint clay. The ware from the two types of kilns was essentially the same.

IV. These brick were from the Southern Ohio district. The two burns showed practically the same quality of ware.

V. These brick contained twenty per cent bond clay and eighty per cent flint clay, part of which was one-half an inch in diameter. These large particles of flint clay often protruded from the sides of the fire brick as they came from the tunnel kiln. A great many surface checks were found in the brick coming from the tunnel kiln. The brick were also weaker than those from the regular burn, showing that the surface cracks evidently extended throughout the brick.

VI. These brick contained ninety per cent flint clay and ten per cent bond clay. They showed that they had received a harder burn in the tunnel kiln than in the intermittent kiln.

VII. These brick were from the Pennsylvania-Ohio district and were made by the soft mud process, twenty-five per cent bond clay and seventy-five per cent flint clay. The brick were discolored and cracked as they came from the tunnel kiln, showing a large amount of iron both on the surface of and throughout the brick. The ware from the intermittent kiln showed some traces of iron but it was not discolored as was the ware from the tunnel kiln.

VIII. These brick were made with an auger machine from the same batch as given in VII. The stock brick were nearly white, dense and very strong. The ware coming from the tunnel kiln was spotted and slightly weaker.

General Conclusions

I. Fire brick made from calcined clay grog and bond clay may be successfully fired in the tunnel kiln. The quality of the ware coming from the tunnel kiln is of a quality equal to that coming from the periodic kiln.

II. Fire brick made from flint clay and bond clay may be successfully fired in the tunnel kiln. The flint clay, however, should not be introduced in too large particles if the ware is to be burned and cooled in seventy-two hours. If some of the flint clay has been previously calcined very good results are secured.

III. When the bond clay becomes dense at a low temperature, difficulties are liable to arise when such a clay is burned in the tunnel kiln. Bricks of types seven and eight show this. It is believed that such brick, those which become very dense, should be fired to a lower temperature, or else be fired in a longer tunnel kiln. Either one of these procedures, if followed, would result in the lessening of the severity of the heat treatment.

IV. Iron, if present, results in the formation of dark spots on the surface of the brick coming from the tunnel kiln. If an excess of air is present, such as is found in the periodic kiln, it oxidizes the iron and its color is less pronounced. This excess of air lowers the efficiency of the kiln. As a result, if the high efficiency of the tunnel kiln is to be retained, such iron spots are unavoidable.

V. Brick were also sent through the tunnel kiln which were made by the dry-press method. They were packed in such a way that the original moisture content was present when the bricks were introduced into the kilns. The results were not satisfactory for two reasons. The brick are ordinarily burned to cone 10; here they were burned to cone 14 and in a very short time. As a result cracks were developed. Were the kiln longer the brick would not have been subjected to such a strain during the water smoking period. It is believed that by using a longer kiln that dry-pressed bricks can be set directly on the tunnel kiln car and be burned successfully.

VI. By using a kiln of suitable length, properly proportioning the raw materials, properly sizing the raw materials, and burning to a proper temperature there appears to be no reason why all refractory fire clay brick can not be successfully burned in the tunnel kiln.

Recommendation

The Committee has decided not to make any recommendations or to arrive at any conclusions in this preliminary report. It is intending to visit two other plants and to conduct burning tests on silica refractories. It is hoped that all the information necessary to make the final report will be in hand before the Annual Meeting of the Association in March, 1922.

S. M. Kier, *Chairman*,
A. F. Greaves-Walker

OBSERVATIONS OF FISHSCALING OF GROUND COAT ENAMELS[1]

By B. T. Sweely

The subject of fishscale is an old one with enamelers and always a live one, for like other evils of this vale of tears, it is always with us. The theories advanced as to its cause, and the remedies and solutions put forth for its prevention, are as numerous as the men engaged in the industry. As each of us has at least two or three pet theories he will gladly expound on the slightest provocation. It was not until recently, however, that accurate data on the physical properties of enamel and steel were presented and their relation to the development of fishscale shown.

Danielson and Souder[2] have shown very nicely that the phenomena of fishscale is intimately connected with compressive stress in the enamel. While many factors are undoubtedly operative in addition to differences in coefficient of expansion of the steel and enamel, the conclusion reached by these investigators is that the fundamental cause is due to compressive stress, and that the ideal solution would be an enamel in which this stress was very low or entirely absent. Such a result is to be attained by compounding an enamel whose coefficient would be equal to that of steel, or so alleviate the stress in the average enamel that failure in the characteristic fishscale form would not occur.

During one of the spasmodic occurrences of fishscale in our plant, the writer sought to test the validity of this idea by removing the enamel from one side only of a piece of ware on the assumption that, if the enamel was in compression, the removal of it from one side of the steel should throw the entire stress, formerly taken by the inner and outer coats, upon one coat and result in an exaggerated case of fishscale over the area from which the one coat of enamel was removed. This was accomplished by placing two or three hundred cc. of concentrated HCl in a basin and allowing it to stand over night, which completely dissolved the first coat on the inside of the basin.

On the trial so treated, the area of first coat removed on the inside is very sharply defined by the fishscaled area on the outside of the piece. While there is some evidence of fishscale at other points on both inside and outside of the basin, over the area defined by the dissolved inside first coat a very pronounced case of fishscale has developed.

In order to find if this result was in any way due to hydrogen penetration of the steel after the first coat was dissolved, and also whether a piece ground coated on one side only would develop the same result, a basin was coated on the outside only with the same enamel and the same acid test made as before. No fishscale developed over the area subjected to the acid treatment, nor is the piece at any point decidedly fishscaled.

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[1] Enamels Division, St. Louis Meeting, Feb. 28, 1922.

[2] Danielson and Souder, *Jour. Amer. Ceram. Soc.*, **4**, 620 (1921).

The next was an endeavor to produce a ground coat whose coefficient of expansion was high enough to practically eliminate compressive stress in the enamel, and subject such a piece to the same acid test. The enamel was based on the conclusions reached by Danielson and Souder, and had the following theoretical composition—

	Melted %
Feldspar	55.0
B_2O_3	5.0
Kryolith	12.0
Na_2O	10.0
CaF_2	7.5
BaO	10.0
CoO	0.5

The theoretical cubical coefficient of this enamel according to the factors given by Mayer and Hovas[1] is 432×10^{-7}. The figure given by Danielson and Souder for average steel is about 384×10^{-7}. Considering these factors, it is obvious that if both were absolutely true, this enamel should be in tension rather than compression, and if the difference is sufficiently great the enamel should craze rather than fishscale.

Samples were coated with this enamel and treated with acid as before. There was no evidence of fishscale shown at any point on the piece; the removal of the enamel from the inside of the basin having resulted in no sharply defined area of fishscale, as was shown on Sample 1. Further when applied in a rather heavy coat, and with the light falling at just the right angle, craze lines can be faintly seen, indicating that the assumptions made in compounding the enamel were at least partly correct.

The above data would seem to indicate that the solution of the fishscale problem was well within reach, all that is necessary being to make up an enamel whose theoretical coefficient is well above that of steel, and forget our past experience with fishscale and all its puzzling losses. Actually, however, the commercial use of an enamel of the above type is practically impossible. The very high content of fluxes of this enamel makes its heat range very short, and its use in the average plant is not feasible. Continued experiments along these lines by the writer have seemed to indicate that under our factory conditions any composition whose theoretical coefficient amounts to approximately 400×10^{-7} will not fishscale. With this fact as a ground work, an interesting field for investigation is thrown open.

We have not as yet reached a point in our experimental work that would lead us to believe that a panacea for all fishscale is within our grasp, but it does seem obvious that we can at least reduce the tendency for this defect to develop under any given set of conditions.

[1] Mayer and Hovas, "Coefficient of Expansion of Enamels and Their Composition," *Sprechsaal*, **44**, 188 (1911).

An interesting development of the above experimental work was the application of this test to ground coated ware on which various compositions had been fired to different degrees of maturity. It was found in nearly every case that the harder a piece was burned, the greater the tendency to fishscale for any given enamel and, in all but a few cases, very little fishscale would occur under the test on a piece that was decidedly underburned.

A point in connection with the data herewith which I believe should be emphasized is that too much dependence can not be placed on the theoretical values arrived at in calculating the coefficient of expansion of an enamel from the tables of Mayer and Hovas or Wenkleman and Schott. It has been the writer's experience that of two enamels whose coefficients may be exactly the same theoretically, one may fishscale and the other will not. If our assumption is true that compressive stress is the cause of this phenomena, then it must be that the degree of volatilization of those fluxes supposed to impart a high coefficient of expansion to an enamel must play an important part. For this reason the intensity of the smelting treatment, the content of easily volatilized fluxes, etc., will all be operative, and it does not seem possible to lay down a hard and fast rule that will hold under all conditions.

These variables may account in part for the often cited case of a ground coat enamel working satisfactorily in one plant and failing completely in another. It is my opinion that we are nearing a solution of this troublesome question in which the work of the Bureau of Standards is to play no small part, in that we have at last a definite cause assigned for the trouble, *i. e.*, compressive stress. Should future developments prove that we are not mistaken in the above conclusions on the occurrence of fishscale we will need only look over our factory practice to determine why the compressive stress in our enamel is greater than at some time when our ware was free from this defect and correct the trouble at its source.

While this seems a simple and obvious remedy, there is little doubt but that much long and tedious experimental work is still before us, and that the ultimate solution will be a matter of long continued research and development.

CERAMIC LABORATORIES
COONLEY MANUFACTURING CO.
CICERO, ILL.

Discussion

MR. WIESTER:—I would like to ask if Mr. Sweely means that overburned ground tends to fishscale more than underburned ground.

MR. SWEELY:—That has been my experience.

MR. WIESTER:—On any kitchen product such as a teakettle the enamel on the bottom is always a little heavier and a little bit underburned, and that is where most fishscaling comes.

MR. SWEELY:—I think that that goes back to the question of Mr. Danielson's investigation on the spinning, the working of the steel. That is true. A piece of steel that has not been spun or worked will fishscale worse than over the area that has been worked. The bottom is usually not worked, spun or stretched in the forming operation; it is the sides that get worked.

Mr. Geisinger's observations do not check with my experiments. A basin coated with the same enamel as used in the acid test described but applied only to the outside, and subjected to the same acid treatment as was used on the fishscaled samples showed no fishscaling. I have checked this a number of times with different compositions but have never had a sample develop fishscale under this test.

BY E. E. GEISINGER:—It appears that the following experiment would rather upset Mr. Sweely's suggested explanation that the fishscaling was caused by the releasing of a strain in the enameled ware. Our ware is enameled on one side only, which accounts for our method of attack.

About three years ago, our enameling superintendent suggested that the laboratory staff try the following experiment and if possible give the reasons for the results. Small test dishes, measuring 6″ in diameter and pressed from $^1/_4$″ thick steel, were enameled upon the inside only. They were then placed in approximately 20% solutions of nitric, hydrochloric and sulphuric acids, respectively. After allowing the steel dishes to be attacked by the acid for about 8 hours, we were very much surprised to see that the enamel was fishscaling upon nearly all the cups. Very little of the steel had actually been eaten away, and we could not explain the reasons for the fishscaling. Mr. Treischel at General Electric Co. has suggested hydrogen penetration as a course for chipping, and it is possible that this is the cause but the proof is not well based.

BY R. R. DANIELSON:[1]—It would seem that the relative expansion of the steel and enamels was a factor in the ability of the enamels to adhere when the vessel was treated with acid, inasmuch as the enamel compounded to have a higher coefficient of expansion than the steel did not develop fishscaling when treated with acid. While the hydrogen penetration, as pointed out by Mr. Geisinger, might tend to loosen the enamel, undoubtedly the hydrogen penetration in the tests which Mr. Sweely made would be as great with one type of enamel as another, and it is to be recalled that only the enamels having a low coefficient developed the defects upon treatment with acid.

R. R. DANIELSON:[2]—The coefficient of expansion of the enamel referred

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[1] Received May 22, 1922.

[2] Received June 29, 1922.

to in Mr. Sweely's paper has been determined by Mr. Souder of the Bureau of Standards. The frit as used by Mr. Sweely was ground with 7 per cent of Johnson-Porter clay and 1.5 per cent of borax. The determination was made on the milled enamel with the following results for linear contraction:

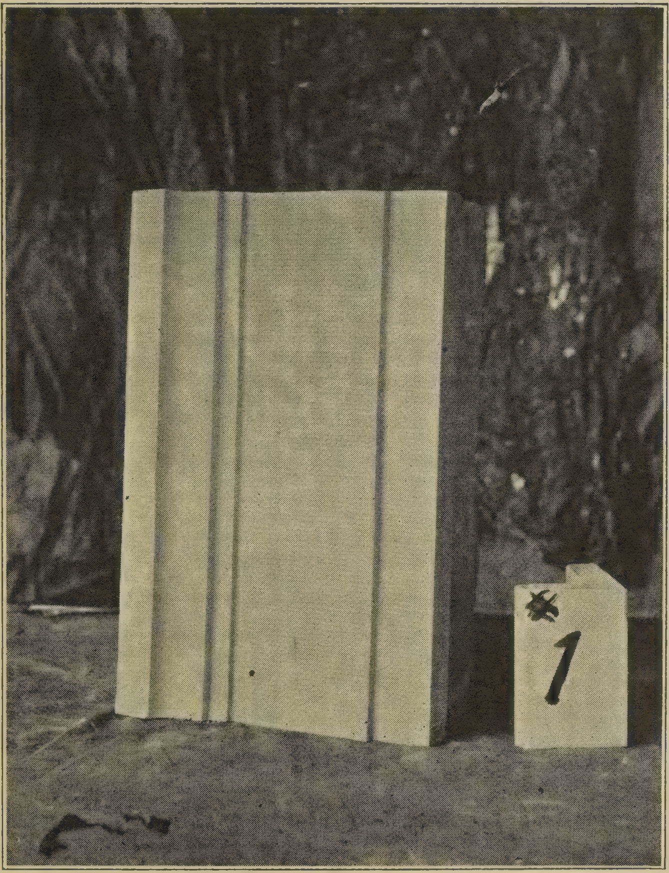
Temperature range	Average coefficient of contraction
400° to 200°C	14.2×10^{-6}
200° to 20°C	12.7×10^{-6}

It is interesting to note that the values given by Mayer and Havos and used by Mr. Sweely in computing the coefficient of expansion were based on determinations from 0 to 100°C, and that the computed value is approximately the same as that for the actual values determined by Souder in the range 20° and 400°C. The Bureau's value in the range 20° to 200°C would be low as compared with that computed from the values from Mayer and Havos.

PRESSING TERRA COTTA

By John Clark

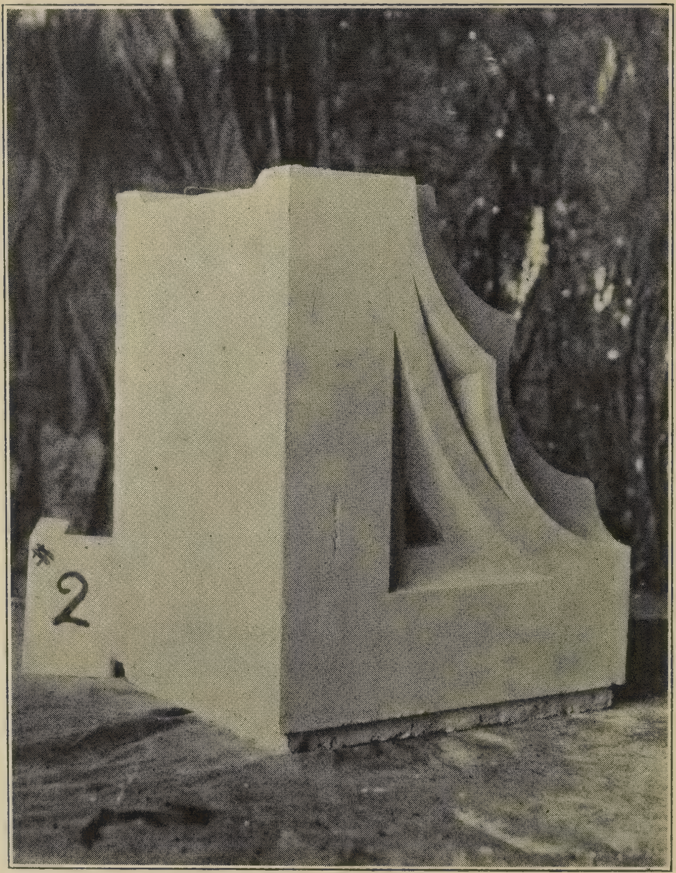
It is my belief that the question of proper pressing of terra cotta should have careful consideration. Failures of terra cotta at the building are more often due to some fault in pressing than to any other cause.



The American Ceramic Society and individual manufacturers have studied the problems of bodies and glazes with resulting great improvements. The work which has not received the study and attention it requires is the pressing. I might also include finishing, but this to my mind is not so important as the pressing.

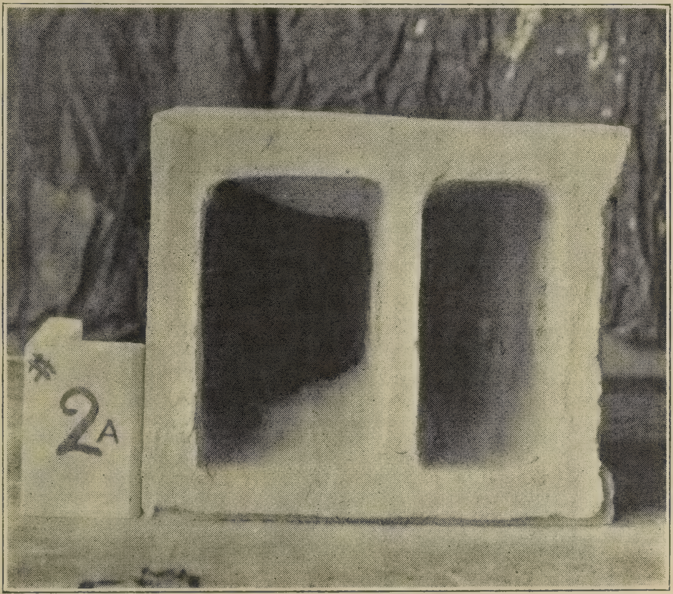
The preparation of bodies and glazes being well done, it is equally important that the pressing should be well done if the piece is to stand the strain that is to be put upon it when placed in the building. Given a body of the right proportions of clays and grog, and properly tempered by thorough pugging, it is then for the presser to make the piece, and this is where improvement must be made.

After a piece of work is turned out of the mold it should show no seams either on face or sides, and the struts or partitions should be so well worked and welded into the sides that to all intents and purposes it is one piece of clay. In many cases when a piece is turned out of the mold, instead of one piece of clay there are five, the sides, ends, face, and as many more as there are struts in the piece.



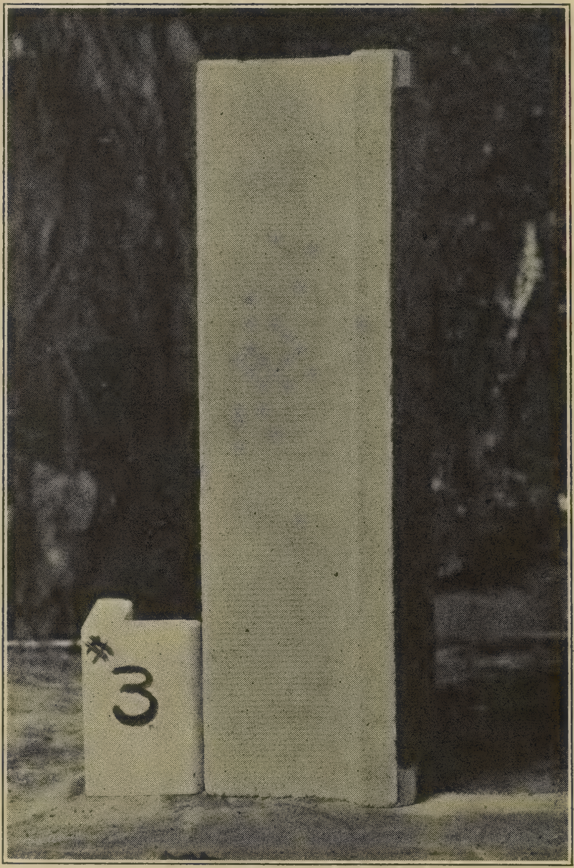
To get a good press the clay must be pressed: Pressure must be applied to the clay after it has been put into the mold, and all of the vertical and horizontal corners welded together. The presser, after the face is in place, generally puts in the ends next, and brings it up to the required thickness. This is not the way to produce the strongest piece of work. The sides should be put in first and the ends last, so that there is a greater opportunity to wedge the ends to the sides.

Too many pressers in working up the face bring up some of the clay to a distance on the sides of the mold until it is as thin as paper. This is a bad practice for if the molds are at all dry this thin clay dries out very rapidly, and when the upper layer is put upon it proper adhesion between the two can not be had. This shows after burning by this thin layer having shrunk away. The point of a knife inserted between the two surfaces will cause this layer to split off readily. The same thing would result from freezing.

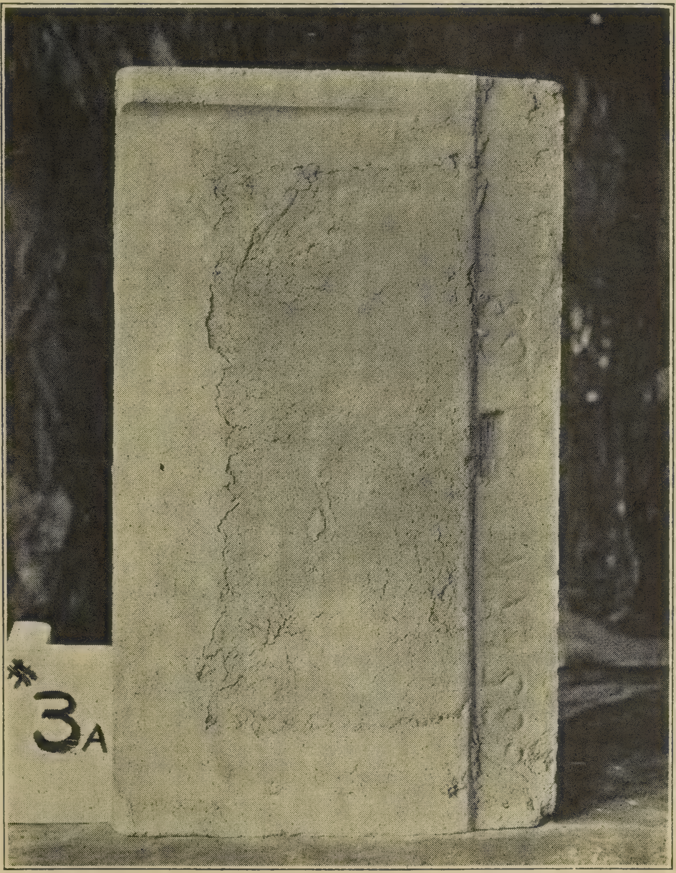


Too many pressers do not understand the nature of clay. Because it is a soft sticky material they expect it will easily bond together and that placement in the mold is merely to give it shape. There is a common notion also that it is only necessary to press the face well, doing the rest of the piece in the easiest and quickest way possible.

Care Required in Drying.—After the piece has been pressed, care should be taken that it does not stay too long in the mold before being turned out on to the board, especially when there are projecting parts on the face or sides, such as dentils, slots for steel forms, and in large cornice sections where the washes, instead of having an angle back to the bond, have a curve. All of the projecting parts on the interior of the mold begin to act as a wedge as soon as the clay is placed between them, by reason of the shrinkage of the clay. Those pieces having a curved wash in many cases develop an incipient crack owing to the greater projection pulling away from the bond while in the mold, which upon turning out on to the board is invisible and does not show until the piece is thoroughly dry, and in some instances not until it comes from the kiln. If such a piece of terra cotta is put into a building these projecting parts, especially ornaments, will shelve off due to lack of sufficient bond to withstand the disrupting action of freezing water.



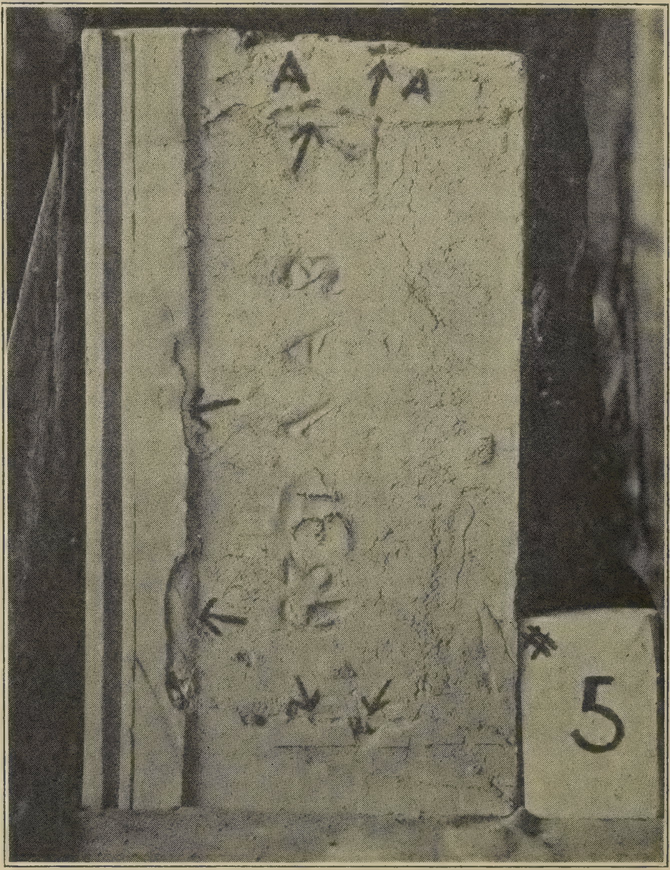
Finishing of Terra Cotta.—A well-pressed piece needs very little finishing, especially where it is tooled. Smooth ashlar work may be made out of shape by the movement of the clay structure, while the finisher is working upon it. The filling up of seams is a subterfuge, because the clay is only rubbed over the surface and smoothed with the scraper. The piece can, in many cases, be pulled apart showing the seam almost through to the interior. These seams may go through the various stages of manufacture, and after the pieces have been placed in the building, they may open up by the expansion and contraction due to heat and cold.



Pressing can never be done too well. A well-pressed and thoroughly burned piece, in which the sprays, glaze and body are of the right coefficients of expansion and properly cooled, should stand all that is required of it when set in the building.

Illustrations of good and bad practices: The photographs of pressed or burned pieces submitted herewith illustrate some of these points.

Photograph No. 1 shows a piece which has been well-pressed. It required very little finishing. Had this not been well-pressed the presser would have had to go over the various members with finishing tools. In nine out of ten cases he would not have improved the lines, but on the contrary they would have been more or less awry.

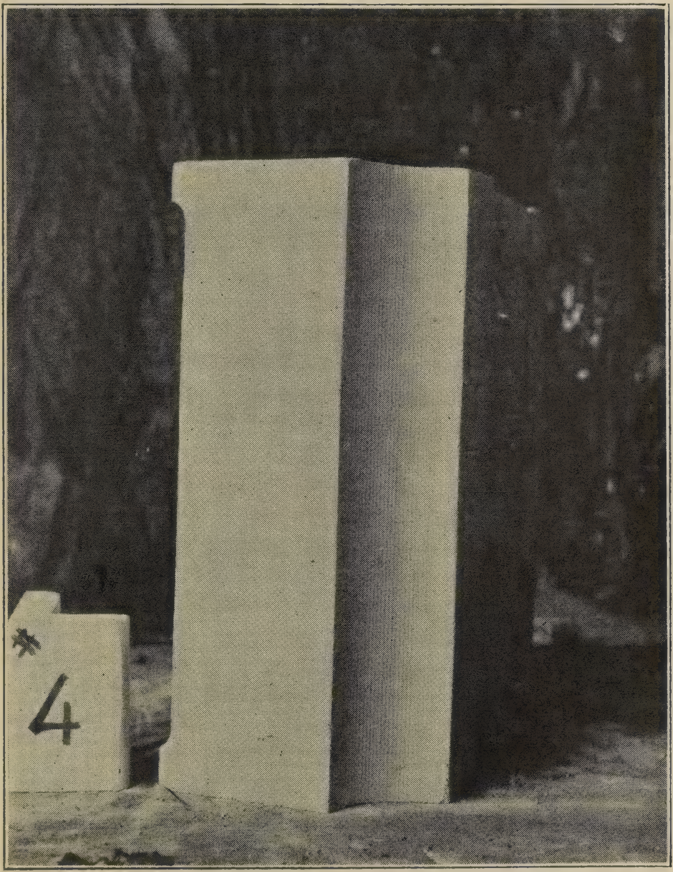


Photograph No. 2 shows a piece that has been well-pressed, with no finishing. This piece although rather complicated is as well bonded as if it were one piece of clay.

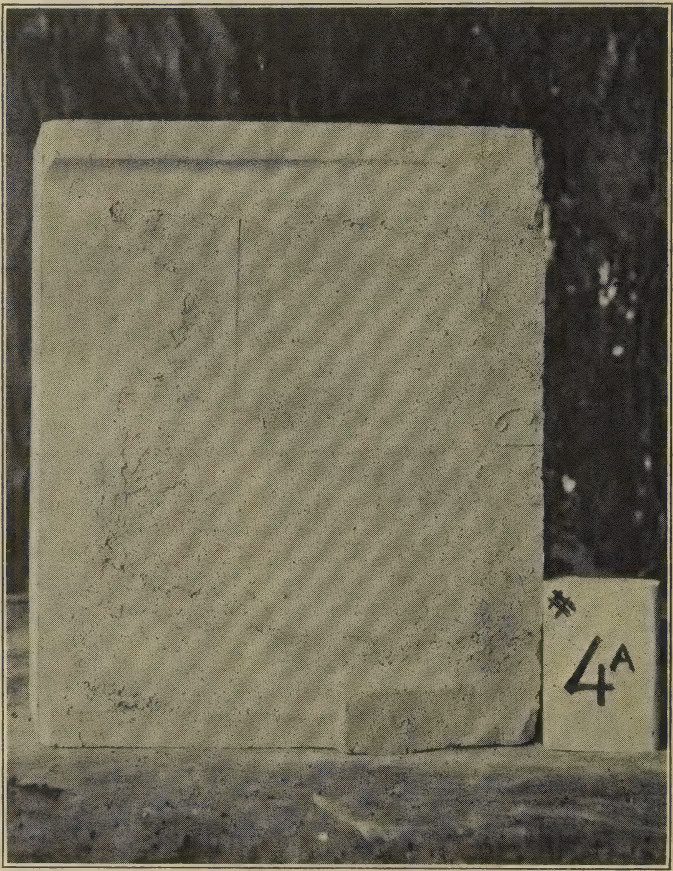
Photograph No. 2-A shows the interior of the piece. There is an entire absence of cracks between the ends and sides, and between the struts and the sides.

Photographs No. 3 and 3-A show a piece which is not so badly pressed on its face, but the back or wash of the sill is faulty, due to bringing the clay up the sides of the mold until it is as thin as paper. Pieces like this can be pulled apart and one can trace the dividing line right through into the interior of the piece. Many cases of shelving of the face of the work at the building from freezing may be directly due to this cause.

Photograph No. 5 is very similar to photographs 3 and 3-A except that the piece has been burned. Note how it has slivered at all the arrow points, and at points "A" the corner has fallen off completely. Pieces of the type represented by 3, 3-A and 5 are very dangerous ones in a building. Unless these seams are crammed and the clay well worked into them the water will find its way into these seams and with alternate freezing and thawing, they will be gradually forced apart. As pieces of this type, (sills, washes of cornice, etc.), have a large area exposed to the weather, it is of the utmost importance that they be a well-pressed piece of clay over their entire surfaces.

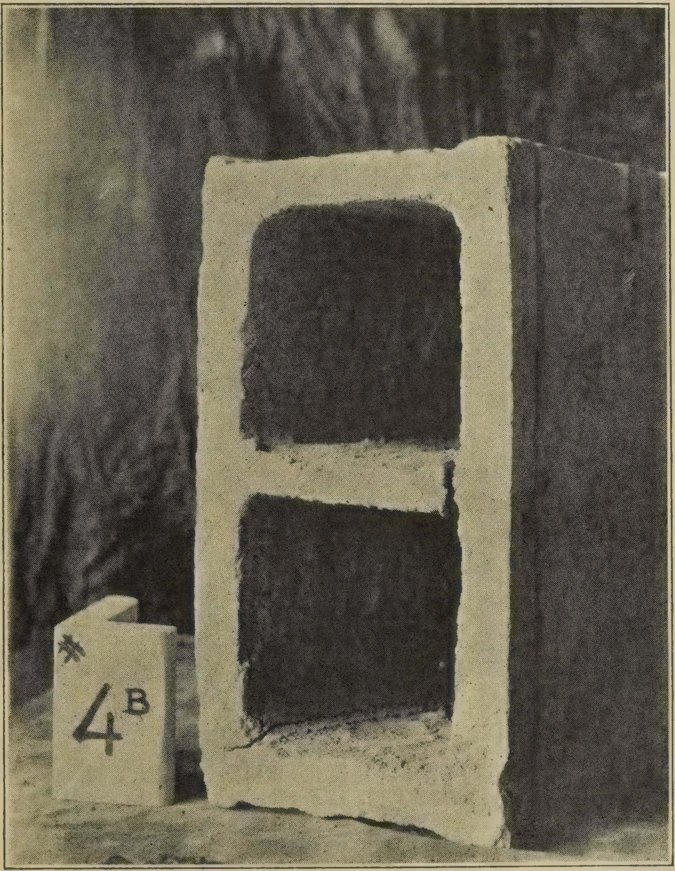


The face is a fine piece of pressing, but the back (No. 4-A) has not been properly pressed. Photograph No. 4-B shows that it is cracked at each end, and also that the strut has parted from the side. While this piece has been taken in a vertical position its position in the building is a horizontal one. With the cracks at the two corners and in strut it is quite conceivable that when the weight of the wall is brought to bear upon it, it will give way. This illustrates that the long sides in pieces of this character should be pressed first and the ends last. There is less tendency to crack when made this way, and even if it should crack it is not so serious as when the crack is vertical or nearly so.



These observations have been chiefly made in two plants, and among pressers who have worked in the various plants of the country. From my experience with pressers the tendency to poor work is on the increase and it is therefore very important that all companies coöperate in training men who will really press work and not produce tonnage only.

There is no process in a terra cotta plant that needs more careful watching than the pressing. The piece produced by the presser is almost the end; all processes previous to pressing are means. The processes after pressing have been well studied and standardized but the pressing has not received the attention it should. It is of the greatest importance that the pressing be well done if terra cotta is to hold its reputation of being good building material.



N. Y. Architectural Terra Cotta Company
Long Island City, N. Y.

GOOD AND BAD PRACTICE IN THE PRESSING DEPARTMENT

By T. A. Klinefelter and F. C. Parsons

Introduction

One of the vitally essential departments in a terra cotta plant is the pressing shop. Here the terra cotta is actually made, and receives its initial handling. Every shop has developed both good and bad practices, all its own, and methods of handling minor details peculiar to its peculiar condition. There are, however, a good many things of general interest to all terra cotta manufacturers, which may be discussed profitably.

So far as the shop itself is concerned, floor area of the right sort, good light, and proper methods of delivering clay, and taking the ware away, are the main concern. It goes without saying that poor, uneven floors, dim light, and antiquated methods of handling are costly in time, money and quality in any department. It is assumed that this is taken for granted.

Terra cotta is hand pressed. Practically all terra cotta now made is pressed by hand, and not by machine. Various schemes have been devised from time to time to make terra cotta by machine, but so far with little or no success except, perhaps, in small simple designs. Owing to the great diversity of shapes, hand pressing is likely to continue in vogue for some time and even if machines are developed for handling plain shapes such as ashlar, it is hard to see how we can get away from hand pressing on a commercial scale.

As is usual in all hand made work, eternal vigilance is the price of high quality. It is purposed here to point out a few of the things which may happen when the work is done in the wrong manner.

Correct Methods of Pressing

While pressing looks like a rough, crude piece of work, there is a right and a wrong way to do it. In general, what we want is a uniformly thick continuous wall, including face, sides, edges and partitions. We want no laps, no blebs, no lines or planes due to imperfect welding. Experience has shown that the best commercial way to do this is to throw in a good sized roll and pound with the whole hand or fist, using the thumb just as little as possible. If the thumb is used, invariably the clay is not slugged hard enough and wherever the thumb has run along, an imperfect weld and air blebs result.

Method of Building Up Sides.—It is fairly easy to get a good even layer for the face at the bottom of the mold, but unless care is exercised, a continuous run up the sides is not obtained. This is the case where the face is filled flat and the side set in. There is no chance to push and work the sides against the face, hence the imperfect welds. A good sized roll should be pounded in all around, at a greater height than the thickness of the face, being wiped off against the side gradually. Then, when the side goes in, it has a line of clay to push and bite against and is more likely to make a perfect weld.

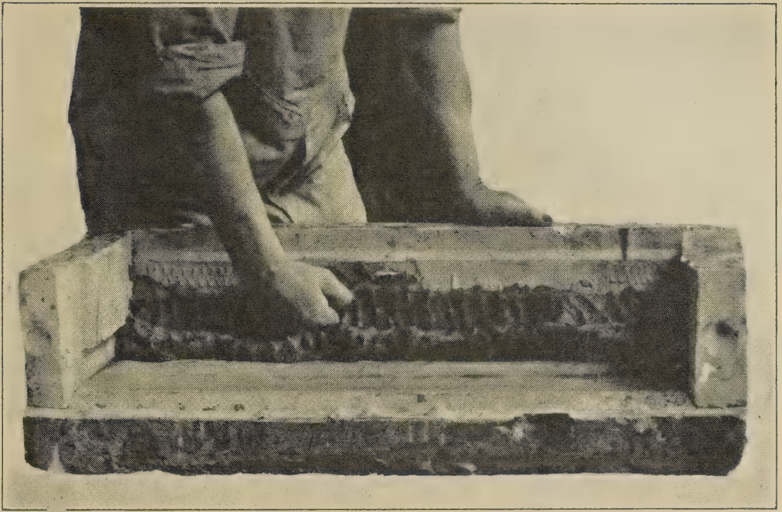


FIG. 1.—Correct pressing along edge. Roll of clay slugged with fist.

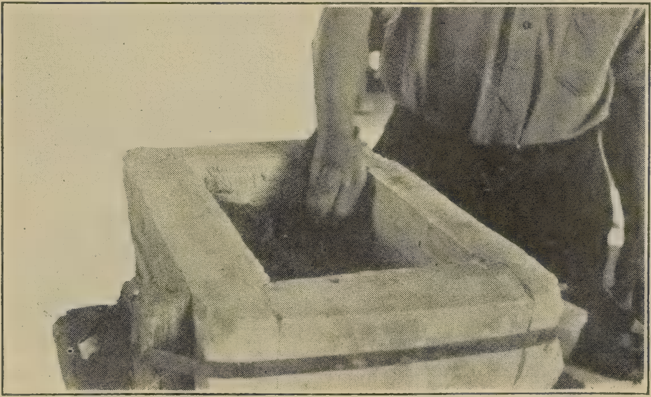


FIG. 2.—Correct pressing in corner.

The corners should be filled in exactly the same way; a roll pounded in with the fist and *not* with the thumb.

Method of Building Partitions.—Partitions are an important part of a piece of terra cotta and may be set in in such a way as to thoroughly bond in with the face and sides, or they may be merely inserted. In some English terra cotta it has been the practice to dust the edges of the partition before setting in so as to prevent it becoming an integral part of the piece. The idea is, presumably, that since the partitions are merely rolled and flattened and not pounded to the same degree as are the sides and face they will shrink more and hence tend to draw the face and sides in if bonded too tightly. However, the advantages of having the partitions well bonded in outweigh these shrinkage difficulites, hence it is a better practice to make as good a weld as possible.

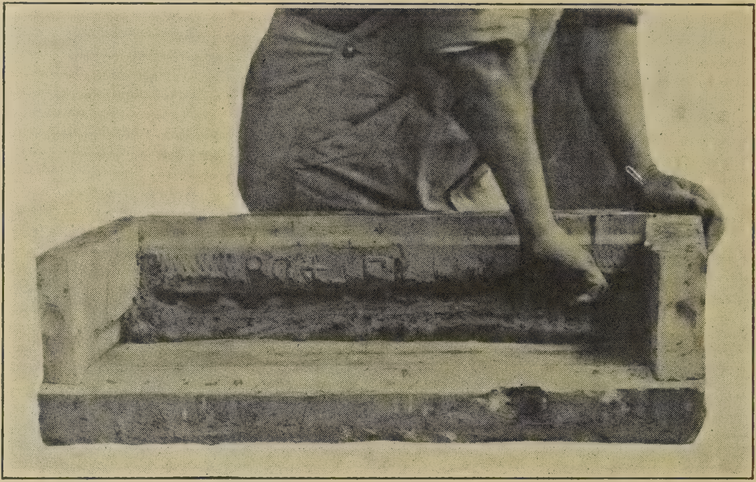


Fig. 3.—Incorrect pressing along edge, "Thumbing." Shows formation of pockets which result in blebs or open spaces.

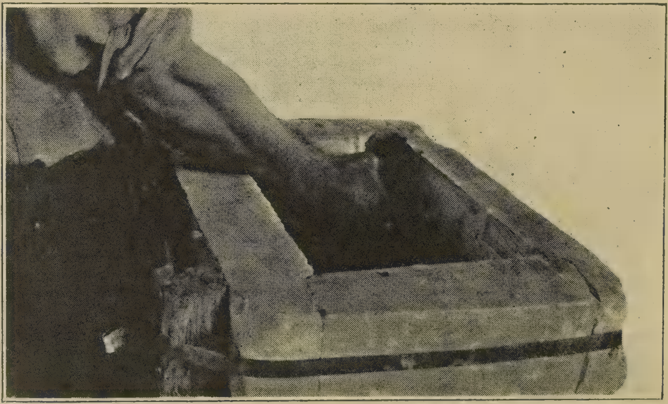


Fig. 4.—Incorrect pressing in corner. "Thumbing."

The proper way to place partitions is to scoop out a good broad, fairly deep channel in the sides, lay the partition in, then lay a roll of clay in each corner and work this roll into the body and partition at one and the same time. The scooping out of the broad trench not only inserts the partitions in the side, but takes away so much clay that the presser is forced to use a roll.

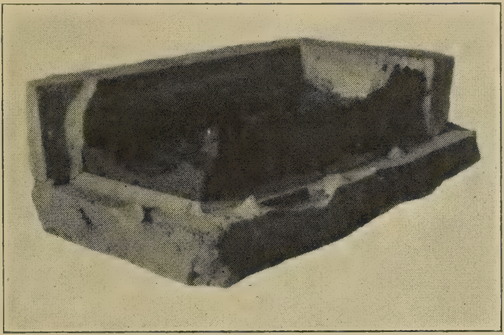


Fig. 5.—Correct. Face is "wiped" up against side in order to give material enough for the side to bond in properly.

Method of Preventing Warping.—In order to hold the pieces to the right shape it is often necessary to make use of a shoe in the pressing. This is merely a flange or ring, fitting down on the mold and projecting over the inside a couple of inches all around. The presser works the clay up against this flange from beneath so as to form a sort of inward lip all around, which stiffens the piece decidedly and counteracts tendency to warp.

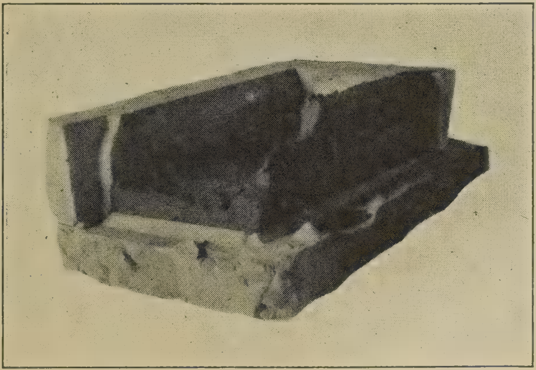


Fig. 6.—Correct. Same as Fig. 5, except showing a side partially worked in. Note that no line of union shows, indicating a strong continuous body of material.

The same thing is accomplished by "flushing over" which is merely a free hand way of doing the same thing, the plaster shoe being omitted. While the shoe might be omitted, since the same thing can be accomplished by flushing, it insures that this extra pressing will really be done without the necessity of constant inspection by the foreman.

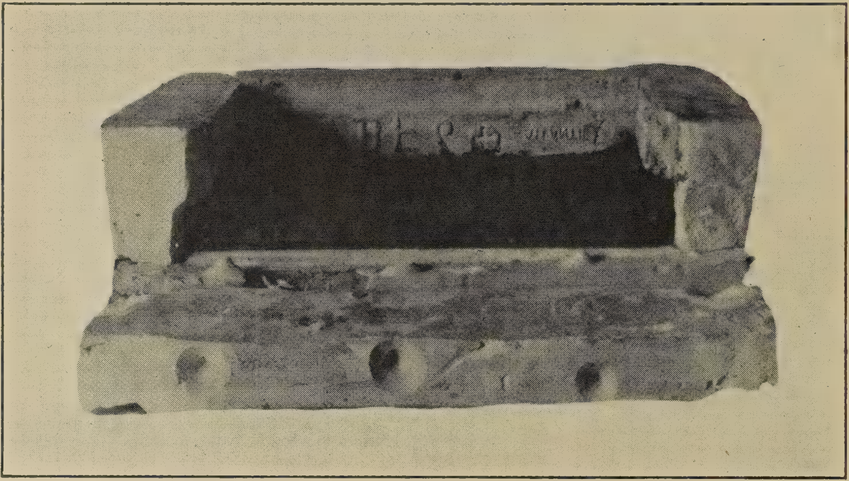


FIG. 7—Incorrect. Face is not "wiped up against sides."

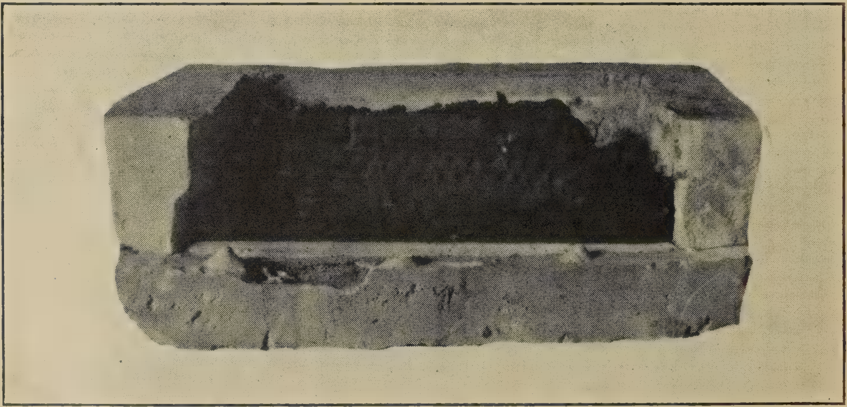


FIG. 8.—Incorrect. Same as FIG. 7, except showing a side set in place. Note the strong line showing at junction of face and side. Piece will be weak along this line.

Sill pieces, which carry a groove for a water bar, is an example of where this extra pressing is of value. The partition through the center tends to draw the surface down at the back where the groove runs, and results in a hollowed surface, so that while the water bar may fit snugly at the two ends it may be almost clear at the center. To counteract the draw of the partition, the flushed over edge is pressed in. This gives a sort of truss, acting at right angles to the draw of the partition and holds the piece straight.

Molding of Projecting Parts.—If there are any projections from the mold into the clay, the clay will hang on these projections and cause cracks to develop. Pieces, such as dentil should not remain in the mold over night.

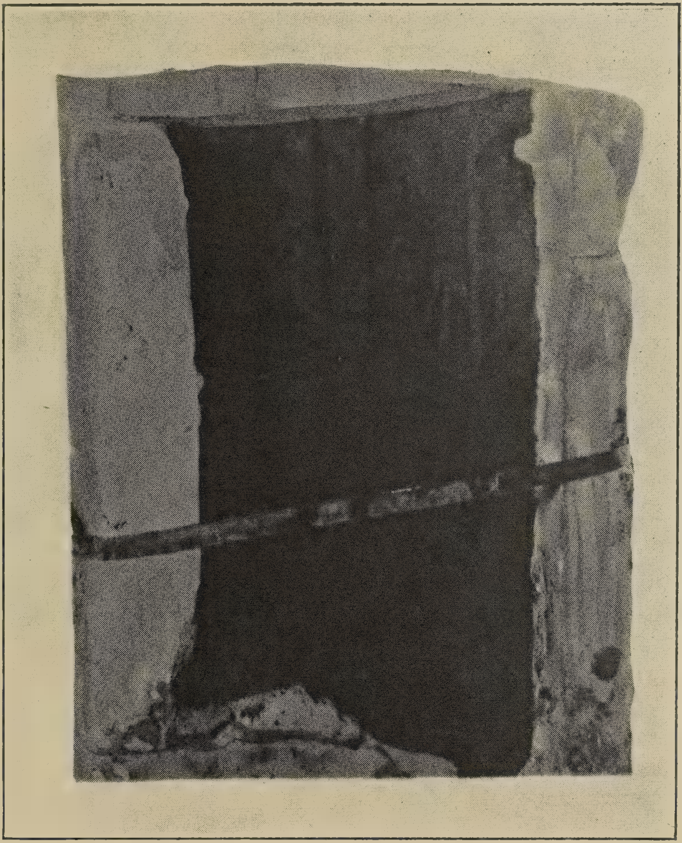


Fig. 9.—Split side mold. Upper right hand corner shows projection for making water bar slot. Note the split in the mold 2 or 3 inches below the projection.

In case a projecting piece shows cracking, one might just as well pull it off, dowel and stick it back on, for otherwise the frost will split it off No doubt some terra cotta has gone to pieces in past years due to this.

In case the projection extends clear across a mold, as in large sills with a water bar, it is often good practice to split the side of the mold. The one piece containing the projection can be removed a few minutes after pressing and the piece then can shrink all it will without the slightest "hanging."

Method of Turning to Obtain Uniform Drying.—After standing in the mold a sufficient length of time, a board is slipped over the top and the whole thing, mold and piece, turned clear over. This is much more important than a great many people think, especially with pieces of such size that the weight of their walls is sufficient to cause sagging. The aim should be to always turn the mold so that the finished surfaces revolve in a vertical plane, or if horizontal, have the mold to support them. Ashlar mitres are especially mean to handle in this manner, and may be completely spoiled at this stage by improper turning.

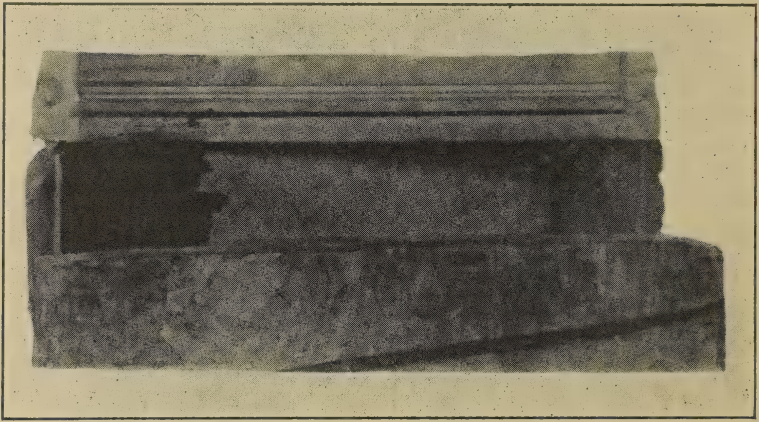


Fig. 10.—Same as Fig. 9, front view. Shows the split part removed and placed above for better inspection. A small portion is shown pressed.

Finishing of Terra Cotta.—After turning out of the mold, the next step is finishing. Generally speaking, the less finishing the better. There are two general methods. The water brush method, and the ordinary with steel and wooden tools.

The water brush method consists of finishing the seams by tool and then going over the surface with a brush full of water. This method has already been described by Hewitt Wilson.[1] It is in use in some places. It is hard, however, to get the pressers to do water brush finishing properly. In order to finish by the water brush properly, the pieces should be finished the same day they are pressed, otherwise the surface may water check. Another bad feature is that the ornament tends to be unduly dulled, and it is generally dull enough as it is.

[1] *Jour. Amer. Ceram. Soc.*, **3**, 114 (1920).

The usual method is to smooth off the surfaces with steel pallates or scrapers. The danger here is largely in finishing too soft or too hard. Too soft gives a wavy surface. Too hard gives a surface on which the slip or glaze does not adhere properly because the surface becomes compacted and does not present the usual open porous condition to which the weight of the glaze has been adjusted. It is almost like trying to spray a hard biscuited piece. Since the slip is adjusted for a fairly porous surface, such a compact surface is likely to result in separation and peeling back of the slip during the burning. Cases have been noted where this condition was so bad that the slip would not stick even in the green state.

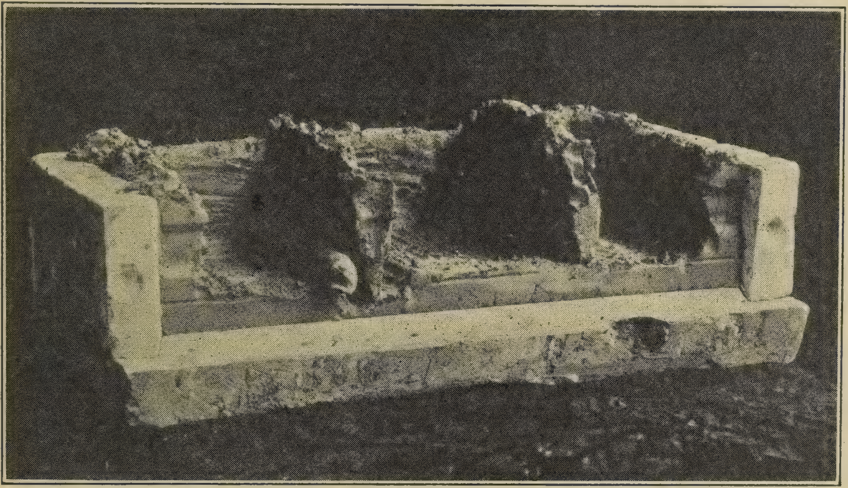
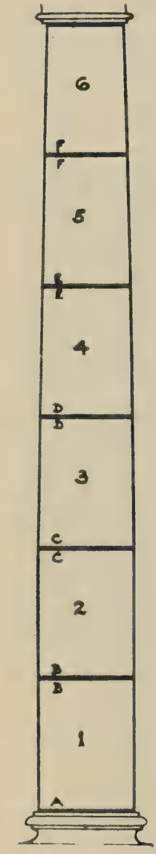


FIG. 11.—Partitions—correct and incorrect. Left hand partition has had groove scooped out, partition set in, and roll of clay laid in (on one side only for better illustration).—Correct. Right hand partition is merely set in against the face. —Incorrect.

Finishing of Columns.—The proper finishing of columns is troublesome. The usual method is to turn out the sections on the boards, and trust to luck that they fit. Usually they do not. One section is almost sure to project a bit over the lower, if it is a drum column, or if fluted, the flutes do not align. If one analyzes the thing, he will note in the case of drums that the end resting on the board does not shrink at quite the same rate as the free end. As this is the case with every drum when an end which has dragged on the board is fitted to the end which has been free to take full shrinkage, the end which has dragged is almost certain to project. The answer is obvious—mark the ends of the drums so that board ends go together, and free ends go together and then when drying has progressed sufficiently to warrant it, stack them on top of one another; finish them as a whole column and let the column dry as a unit.

The flutes not fitting is usually a case of finishing pieces separately, instead of the column being finished as a whole.

In the case of engaged columns or pilasters, the whole unit should be laid out on a single board and finished as a unit.



In handling columns and pilasters, it is assumed that enough molds have been furnished so that the whole unit can be pressed at one time. It would be impossible otherwise to finish the sections together, some of which are several hours drier than others. This matter of wet fitting requires care, but the results attained fully warrant the extra effort. The entasis of columns or batter of pilasters in no wise affects the procedure.

It is possible to manufacture almost any sort of terra cotta shape, provided it is given the proper amount of attention and nursing. This may mean excessive cost, but this really is the criterion of whether a given shape is commercially practical.

ATLANTIC TERRA COTTA CO.
TOTTENVILLE, N. Y.

Discussion

MR. ORTMAN:—Pressing is by all odds the most important operation in the manufacture of terra cotta. Most anyone can eventually work our glazes to fit a body, and it does not take very long to train a man to operate kilns, important and thoroughly technical though these are, but if you do not have a good, strong sound structural piece to start with, you are going to have poor ware.

We have not had, until this time, any paper of this sort presenting the good and bad practices in this most important operation. This is an excellent presentation of an important subject.

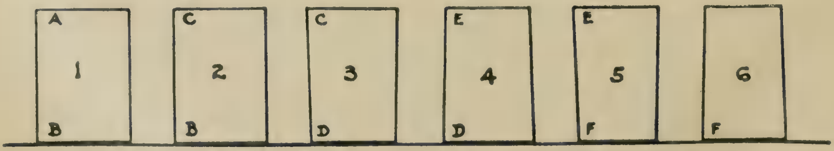


FIG. 12.—Correct method of turning drums of columns out on boards.

MR. W. D. GATES:—I think this is a very important subject. It occurs to me that we have been a little negligent in these practices. A great many defects may be caused by these initial strains that sometimes show themselves as the ware goes on through the factory, and often only after it comes from the kiln or even after it is in the building. These initial strains are caused by imperfect pressing. It is in the pressing that the clay is put into a condition of uneven strain which, afterwards, causes a great deal of trouble.

A MEMBER:—Can a man do just as rapid work by the method proposed by Mr. Klinefelter as by the old method?

MR. KLINEFELTER:—Yes, if you break the presser into that way. He will never go back to the old thumb method. It is easier on the hand and arm. We have no trouble in maintaining this method of pressing under piece work system.

MR. GATES:—One point was not brought out; one layer is put in and then another layer and then the whole is pressed, and then you put in another layer. What do you do in that case?

MR. KLINEFELTER:—We are not advocating any change in the standard methods of pressing, but merely insisting on the use of the side of the hand or fist instead of the thumb.

MR. CLARK:—We are telling our employees all the time to keep their thumbs out of the corners. We have been trying to train the men to keep their thumbs away from the joints and corners, but they will use their thumbs in spite of our instructions.

If we could let the men see the damage they are really doing as shown by the defective pieces and demonstrate to them that afterwards those pieces might fail, we can sometimes show them that they have not paid proper attention to the joining and to the corners.

MR. TUCKER:—Mr. John Clark in his paper on pressing differs with Mr. Klinefelter in the matter of wiping up. On a small mold, Mr. Klinefelter's method might be satisfactory, but, as an instance, on a large ashlar mold, where the perimeter is very large or the area very large, the presser has to put in a large amount of clay for the face and wipe up all around. He wipes up the clay to zero thickness and then proceeds to put in the sides. By the time the presser gets to the third side, the thin wiped-up edges on the sides yet remaining to be pressed are dried out, especially so if he has a dry mold. It is evident that in cases of this sort it is quite difficult to obtain a weld between the fresh clay and the partly driedclay in the mold.

MR. KLINEFELTER:—It has been our experience that the size of the piece has not caused trouble from drying out. Work can be done as rapidly by this method as by any other.

MR. F. B. ORTMAN:—On the point with regard to the pulling in of the sides of the pieces due to the extra shrinkage of the partitions, I might mention that some companies have helped to overcome this trouble by using a clay in the partitions which will shrink less rapidly than does the clay of which the remainder of the piece is made.

On the question of welding of the partitions to the face and sides of the piece, I think that this is one of the most prevalent faults of the average presser. Not long ago I had occasion to visit a job where there was a failure due to movement in the building which caused a crushing strain to be brought on the face of the terra cotta, in some cases shearing the face off entirely, leaving the partitions and voids exposed. While I do not believe that poor pressing was the cause of these failures, in examining same after the face had been sheared off, I saw a great deal of evidence of poor pressing, particularly from the standpoint of welding the partitions to the face. There were a number of instances where the face had broken off from the partition in a clean sharp line without even leaving a mark in the pieces to show where the partition had been in contact with the face, showing clearly that no effort at all had been made to weld the partition in these instances.

If we could always be sure of having the partitions welded in, as Mr. Klinefelter suggests, it would greatly increase the crushing strength of our material in the building.

Mr. Clark:—Mr. Major Gates has a pressing machine that will bind a partition and the sides with the face so that it is impossible to see where they join together. It absolutely is one solid mass; I think that if we will emphasize the importance of good joining of the partition we will do away with a lot of our present troubles. With this machine the operator would not touch the clay. He just lays clay in whatever thickness the face, sides and partitions are to be and the whole thing gets a pressure of from 250 to 300 pounds per square inch. That gives a better weld than any pressure ever born could possibly make.

REFRACTORY CLAYS OF TEXAS

By J. H. Kruson

There are scattered, in different sections of Texas, many deposits of clays which appear to have refractory properties of sufficient value to warrant their use in the manufacture of low grade fire-clay products.

The bulk of the deposits being worked lie in the eastern portion of the State. Fire brick are manufactured at Denton, Elgin, Crush, Hopkins Co.; Butler Spur, Bastrop Co.; Elmendorf; Athens and Sulphur Springs.

These deposits, as a whole, are contaminated with foreign material so that only comparatively small sections are suitable for use. They are associated with lignite, free sand, (silica) running as high as 20%; iron (from 2 to 4%); and often the layers of sandstone separate the strata of clay.

The deposits in the northeast occur in lenticular form and vary in color and volume.

These clays generally are very plastic and dry; they break up in grinding into fine particles.

The following chemical analysis is an average representative of the so-called Refractory Clays of Texas:

	A	B	C
Silica (SiO_2)	70.05	74.04	77.75
Alumina (Al_2O_3)	18.80	15.15	11.04
Ferric oxide (Fe_2O_3)	3.07	0.50	3.19
Lime (CaO)	0.50	0.50	0.84
Magnesia (MgO)	0.30	0.27	0.38
Potash (K_2O)	0.29	0.42	...
Soda (Na_2O)	0.25	1.12	...
Titanic acid (TiO_2)	1.00	1.31	1.23
Water (H_2O)	5.74	6.70	3.75

Due to the peculiar working qualities of these high silica clays, the bricks are manufactured by the dry press process. The necessity for burning them to a temperature of 2350–2450 °F before a good bond is developed may be due to the high silica content. Some grog is also used in the manufacture of these brick.

Fig. 1 will illustrate the refractory nature of these clays. Each sample is from a different location and is representative of the quality of ware produced.

The samples were broken in halves and marked. One half of each brick was subjected to the heat test and results are shown in Fig. 1, under the untested portion of the respective samples.

The samples were subjected to a straight heat test in an oil fired furnace together with samples of brick made from a second grade Missouri fire clay. At 2875 °F the samples showed marked signs of swelling and deforming, which increased slowly until a temperature of 2950 °F was reached,

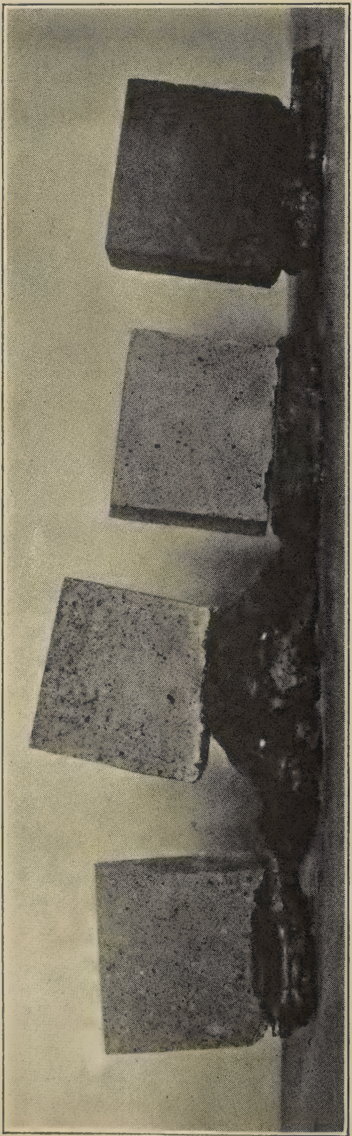


FIG. 1.

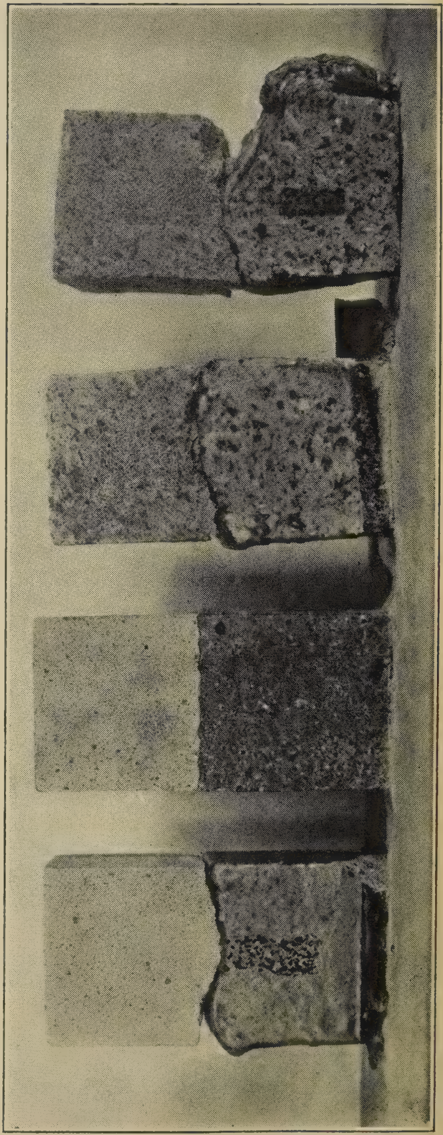


FIG. 2.

after which they failed rapidly and at a temperature of 2990°F (cone 28), they were fused until they had lost their original identity.

Fig. 2 shows the samples of some second grade Missouri fire brick in which grog is used. With these bricks the furnace temperature was brought up to 3000°F in about five hours, and the test completed in seven hours at a temperature of 3050°F or 60°F higher than that to which the Texas samples were submitted.

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ORIGINAL PAPERS

WET PROCESS ENAMELS FOR CAST IRON[1]

R. R. Danielson and H. P. Reinecker[2]

ABSTRACT

Wet process enameling of cast iron is becoming of importance because of its application to the enameling of stove parts, sanitary fittings and hardware. This paper is a report of an extended investigation of wet process enamels for cast iron, in connection with the use of a ground coat.

Compositions used in dry process enameling have served as a basis for the work, which includes a study of ground coats and white cover enamels. The effect of varying methods of preparing the frits, mill additions, and the relation of composition of the enamels to such properties as adherence, texture and opacity have been carefully studied.

Ground Coats.—Sintering of most ground coat frits has been found desirable in order to develop best adherence on the castings. Clay gave best results as a mill addition for the ground coats, and flint and feldspar were found to be less satisfactory. Excessive additions of clay or flint produced flaking of the ground coat while feldspar tended to develop blistering. About 15 per cent of clay or 10 per cent each of clay and flint are recommended as mill additions for the ground coats.

Excessive additions of any one flux were not desirable, and best results were obtained when sodium, lead and boric oxides were combined in more or less definite proportions. Sodium oxide in excess of about 10 per cent gave rise to blistering. Boric oxide increased the firing range of the ground coats and was preferable to lead oxide on this account, although it tended to promote crawling of ground coats high in boric oxide if they were applied somewhat heavily.

The best ground coats developed are Rg-26, 17, 1, 25 and 18.

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[1] By permission of the Director, Bureau of Standards.

[2] Read before the Enamel Division, St. Louis Meeting, Feb. 28, 1922.

Cover Enamels.—Cover enamels were smelted in the usual manner. The mill additions consisted of 5 per cent of clay, 8 per cent of tin oxide, and 45 per cent of water, all based on the weight of the dry frit.

For best results, the cover enamel must be adapted to the ground coat in refractoriness. Boric acid increased the firing range of the enamels but tended to promote crawling, although this was less pronounced in the case of the more fusible compositions. Boric oxide improved the opacity when subsituted for such fluxes as sodium and lead oxides. Cryolite increased opacity but additions above 10 per cent, based on the melted weight, tended to promote crawling. Considering all factors, cover enamels R-14 11, 28, 1 and 18 gave best results.

Introduction

Wet process enameling for cast iron has become of great importance, particularly in the stove industry, within the last few years. This is undoubtedly due to the fact that small castings required for stoves can be handled in greater volume and at less cost by this process. Less skilled labor is required for manipulation and the method lends itself readily to the enameling of irregularly shaped castings.

Very little has been published regarding this method of enameling, although it has been used for some time in the manufacture of cast iron cooking ware. The literature of the American Ceramic Society lacks any reference to wet process enameling of cast iron, and the various treatises on the subject of enameling either make no reference to or are so vague in their treatment of this particular method that they are of no help to those interested in the development of suitable compositions and technique.

The strength of enamels is inversely proportional to the thickness of the coat when the properly balanced composition is used. The heavy coats of enamel as used in the dry process are apt to chip on sharp edges when subjected to impact. The wet process tends to overcome this difficulty as it is possible to apply the enamel in much thinner coats.

Two distinct types of wet process cast iron enamels are commonly used, two or three coat process in connection with the use of a ground coat, and one or two coat process without the use of a ground coat, using one composition for both coats. This paper will treat of enamels that are used in connection with a ground coat and will deal particularly with the development of white enamels.

The method is similar to that for steel enameling, as the ground or first coat is fired and allowed to cool before the cover is applied, while the dry process necessitates sieving on the dry cover before the ground coat has cooled and the return of the casting to the furnace to gloss over the enamel, thus making it impossible to fire more than a limited number of pieces at a time.

Since it was believed that ground coats were as important as the covers, the first principal work has been in the development of suitable compositions for such grounds. The basis of this work consisted of a number of typical ground coats now in use for the dry process. In order to obtain an enamel of the proper fitting qualities and expansion, the above procedure was considered advisable.

In studying cover enamels the same procedure was employed, several enamels which had given good results in commercial practice when used by the dry process being selected as the basis for the studies. This work consisted of noting the effects of variation in composition and heat treatment.

In studying the three coat wet process enamels the methods of preparing the enamels and the technic employed were based on the conclusions drawn from previous preliminary studies.

Preparation of Enamels

In the preliminary study the ground coats were prepared by weighing in five pound batches, mixing thoroughly and smelting in crucibles to the same degree as that for ground coats for sheet steel. It was soon found that the ground coats prepared by this method had very poor adherence so the sintering method was resorted to. The latter gave excellent results and was adopted, therefore, in the preparation of all ground coats used in this investigation. The materials were placed in crucibles and fired in a kiln to the temperature of approximately 975°C (1775°F) over a period of two hours. Upon cooling, the frits were broken from the crucibles and crushed in a jaw crusher to a size suitable for grinding in the ball mills.

The sintering method undoubtedly prevents the volatilization of the fluxes and also results in a ground coat having greater strength than that obtained in the melting of the materials to a glass. These results have been checked with a large number of varying compositions and even in the case of the more fusible grounds the sintering method gave far better adherence, although it is quite possible that satisfactory results may be obtained in the smelting of certain compositions.

The covers were prepared in the usual way by melting, except that the customary content of tin oxide was reserved for the mill addition. The latter consisted of 8 per cent tin oxide, 5 per cent Johnson-Porter Tennessee ball clay, with the necessary amount of water to form a slip for spraying.

The cast iron specimens for test were corner fittings and oval discs used in the manufacture of enameled stoves. They made ideal samples as they had a number of curved surfaces and sharp corners which would accentuate poor adherence of the enamel. The castings were prepared for enameling by annealing at temperatures approximating 815°C (1500°F). They were then sandblasted with a mixture of about 80 per cent sand and 20 per cent crushed steel shot.

The cleaned castings were coated with the various ground coats with a light application by means of an air spray. They were then dried thoroughly and fired in an electric furnace at temperatures varying from 760° to 815°C (1400° to 1500°F). The time of firing varied from five to ten minutes depending upon the particular ground and the type of casting used. After the firing and cooling of the ground coat, they were coated with the cover enamel by spraying. The cover enamel was dried thoroughly, and it is well to emphasize at this point the necessity of thorough drying if crawling of the enamel is to be avoided. The covers were fired at 730° to 760°C (1350° to 1400°F), the time of firing varying from five to ten minutes depending on the refractoriness of the composition.

To note the working qualities of the ground coats in respect to the cover coats, especially as to adherence and texture, enamels R-1 and R-5 (in Table III) were used with each ground coat. R-1 was a medium refractory enamel while R-5 was comparatively soft.

In Table I are shown four basic ground coat compositions giving the melted weights, batch weights and mill additions for each composition. These are typical compositions of ground coats used for dry process enameling of cast iron.[1] Rg-1 is a representative of the flint type with a considerable amount of raw clay in the mill mix. Rg-2 is a combined flint and feldspar type, this ground being a fairly refractory type with small additions of clay and cobalt oxide in the mill batch. In ground Rg-3 is shown a combination of two fusible frits containing large amounts of lead oxide, both the feldspar and flint types being represented. The mill additions consist of medium quantities of clay, flint and feldspar. Ground Rg-4 differs from the other compositions in this series as it has a comparatively high content of boric acid and feldspar. The mill additions consist of a medium amount of clay and a small percentage of cobalt oxide.

Although these ground coats had given very good results when used by the dry process, it was noted that when subjected to the wet process there was considerable variation in such properties as adherence, texture, etc., both in respect to the ground coat and the cover enamel.

Apparently the best results were obtained with Rg-1. This ground coat gave fair adherence, but the most desirable feature was the comparative freedom from pinholes in the cover enamel.

Ground coat Rg-2 adhered poorly to the iron, showing that this type of ground did not have the proper physical properties to withstand the stresses, set up in cooling, without the use of a cover for protection. It also had a short firing range so that there was a tendency for the cover enamel to develop pinholes.

With ground Rg-3, fairly good results were obtained, approaching those of Rg-1, although there was a tendency to develop fine pinholes, especially when slightly overfired.

---

[1] H. F. Staley, Bureau of Standards, *Tech. Paper* **142,** p. 79–82.

When the frit compositions "a" and "b" of Rg-3 were combined to give a single frit, the results differed very much. The resulting ground coat had poor adherence, showing that the physical condition of the enamel is fully as important as its chemical composition.

Ground Rg-4 had very good adherence, but had a decided tendency to form pinholes which may have been due to its fusibility as compared with the cover coats.

TABLE I

GROUND COATS FOR WET PROCESS CAST IRON ENAMELS

FRITS

Composition	Rg-1	Rg-2	Rg-3 a	Rg-3 b	Rg-4
Flint	57.4	24.5	..	42.0	..
Borax	30.2	33.3	20.5	25.3	48.3
Sodium Nitrate	5.7	..	3.6	5.1	3.5
Red Lead	6.7	3.6	22.3	27.6	1.7
Maine Feldspar	..	38.6	53.6	..	46.5
Total	100.0	100.0	100.0	100.0	100.0

MILL BATCHES

Frit	100	100	Frit a: 66.6 Frit b: 33.3	100
Flint	69	..	10	...
Clay (Johnson-Porter)	36	6	10	15
Cobalt Oxide	..	0.33	..	0.33
Maine Feldspar	..	..	16	...

Since Rg-1 with a high content of raw mill additions had fairly good adherence and the covers applied to this ground gave the best results as to texture and opacity, it was decided to study the effect of varying mill additions. Since Rg-1 contained a considerable amount of flint and clay, it was planned to study the effect of replacing the flint by feldspar and clay, and also the replacement of clay by flint and feldspar, simply retaining enough clay to float the frit. In this procedure it was hoped that a composition might be developed which would have good adherence as well as the other desired qualities. In making these substitutions, the ratio of fusibilities, as suggested for various enamel refractories by Coe[1] in his work on ground coats for cast iron, was used. Coe gives the following ratio: 40 clay equals 66 flint equals 100 feldspar, and the substitutions were made in Rg-1 on this basis.

---

[1] J. H. Coe, "Compositions of Commercial Ground Coats for Cast Iron Enamels," *Trans. Amer. Ceram. Soc.*, **13**, 531 (1911).

In Series 1, Table II, ground coat 1B-Rg-1 has the flint addition in the mill batch of Rg-1 replaced by clay in the ratios given by Coe. This should result in a composition with the same refractoriness as Rg-1. To the remaining members of the series, clay has been added or subtracted in units of 15.5 parts.

Table II shows very clearly that with the increase of raw additions in the mill batch the adherence is not satisfactory, except in Series 1 where several compositions with a high clay content had fair adherence. Later these were found to be undesirable as commercial compositions because the results were not consistent over a large number of trials, there being a tendency for chipping to develop in some cases. In Series 2 and 3 with flint or feldspar substituted for clay the adherence was very poor except where the additions were small. It will, therefore, be noted that flint and feldspar are poor substitutes for clay in the mill additions for ground coats, as they evidently detract from the adherent quality of the enamel.

TABLE II

EFFECT OF VARIATIONS IN MILL ADDITIONS

Frit Constant 100 Grams

Specimen	Clay	Flint	Feldspar	Adherence		Cover pinholes
				Ground coat	After applying cover	
1E-Rg-1	108.5	...	...	Flaked	...	..
1C-Rg-1	93.0	...	...	O. K.	O. K.	None
1B-Rg-1	77.5	...	...	O. K.	O. K.	None
1A-Rg-1	62.0	...	...	O. K.	O. K.	None
1D-Rg-1	46.5	...	...	O. K.	O. K.	Few
1F-Rg-1	31.0	...	...	O. K.	O. K.	Few
1G-Rg-1	15.5	...	...	O. K.	O. K.	Few
IIC-Rg-1	6.0	114.0	...	Flaked	...	..
IIB-Rg-1	6.0	120.0	...	Flaked	...	..
IIA-Rg-1	6.0	96.0	...	Flaked	...	..
IID-Rg-1	6.0	73.0	...	Chipped on edge	O. K.	None
IIE-Rg-1	6.0	48.0	...	Chipped on edge	O. K.	Many
IIF-Rg-1	6.0	24.0	...	O. K.	O. K.	Many
IIIC-Rg-1	6.0	...	216.0	Flaked	...	..
IIIB-Rg-1	6.0	...	180.0	Flaked	...	..
IIIA-Rg-1	6.0	....	144.0	Flaked	...	..
IIID-Rg-1	6.0	...	108.0	Flaked	...	..
IIIE-Rg-1	6.0	...	72.0	O. K.	O. K.	Few
IIIF-Rg-1	6.0	...	36.0	O. K.	O. K.	Few

Since it was concluded that an excessive amount of raw material in the mill batch was detrimental to the desired results, it was decided to make a study of the effect of variation in the composition of the frit, using 15 per cent of clay in the mill batch, approximately the maximum amount consistently giving proper adherence. Ground Rg-1 was taken as a basis for this work. The different substitutions were made within the limits of workable ground coats. The latter must necessarily have the correct physical properties to permit them to undergo three distinct firings without blistering.

The melted and batch weights of the 21 ground coats studied are given in Tables III-H and III-I.

TABLE III-A

FLINT–PbO SERIES

The Effect of Varying Flint and PbO in Ground Coats.
Constant Portion Melted 22.10,—13.57 B_2O_3, 8.43 Na_2O.
Variable Portion Melted 77.90,—Flint and PbO

Number	Melted weights		Remarks		
				Texture	
	Flint	PbO	Adherence	R-1	R-5
Rg-5	73.50	4.40	Crawled	..	..
Rg-1	69.90	8.00	Good	Good	Good
Rg-6	66.30	11.60	Good	Fair	Good
Rg-7	62.70	15.20	Good	Fair	Good

TABLE III-B

B_2O_3–PbO SERIES

The Effect of Varying B_2O_3 and PbO in Ground Coats.
Constant Portion Melted 78.43,—69.90 Flint, 8.53 Na_2O.
Variable Portion Melted 21.57,—B_2O_3 and PbO

Number	Melted weights		Remarks		
				Texture	
	B_2O_3	PbO	Adherence	R-1	R-5
Rg-16	21.57	0.00	Good	Few Pinholes	Good
Rg-17	17.57	4.00	Good	Good	Good
Rg-1	13.57	8.00	Good	Good	Good
Rg-18	9.57	12.00	Good	Good	Good

For comparison of the various compositions and their properties, it is possible to group the ground coats according to variation in the melted weights as shown in Tables III-A to III-G inclusive.

Table III-A shows the effect of replacement of quartz by lead oxide. The adherence of the ground coat apparently is benefited by the replacements noted. Rg-1 with 70 per cent of flint evidently contains the maximum amount of flint for workable ground coats. There is apparent in the study of cover coats as applied to these ground coats a tendency for the more fusible covers to give the most satisfactory enamels. The refractory covers not only produce blistering of the ground coat in the firing necessary to give the covers desirable gloss and finish, but portions of the over-fused ground coat are absorbed by the cover causing black specks in the resultant enamel.

As a whole, the lead-oxide boric-oxide series (Table III-B) gave very good results. However, in Rg-16 with the replacement of all the lead oxide by boric oxide, there was a tendency of the ground coat to crawl in firing and for the boric acid to crystallize from the enamel if the latter was not used very soon after milling. The crawling is undoubtedly due to the higher viscosity imparted by excessive boric oxide. This, with the crystallization noted, would indicate an excess of boric oxide in the enamel. Replacing lead oxide with sodium oxide (Table III-C) gave compositions which had a decided tendency to develop pinholes.

TABLE III-C

Na_2O–PbO SERIES

The Effect of Varying Na_2O and PbO in Ground Coats.
Constant Portion Melted 83.47,—69.90 Flint, 13.57 B_2O_3.
Variable Portion Melted 16.53,—Na_2O and PbO

Number	Melted weights		Remarks		
				Texture	
	Na_2O	PbO	Adherence	R-1	R-5
Rg-19	16.53	0.00	Good	Many Pinholes	Many Pinholes
Rg-20	12.53	4.00	Good	Few Pinholes	Few Pinholes
Rg-1	8.53	8.00	Good	Good	Good
Rg-21	4.53	12.00	Good	Few Pinholes	Good

TABLE III-D

FLINT–FELDSPAR SERIES

The Effect of Varying Flint and Feldspar in Ground Coats.
Constant Portion Melted 30.10,—13.57 B_2O_3, 8.53 Na_2O, 8.0 PbO.
Variable Portion Melted 69.90,—Flint and Feldspar

Number	Melted weights		Remarks		
				Texture	
	Flint	Feldspar	Adherence	R-1	R-5
Rg-1	69.90	...	Good	Good	Good
Rg-9	...	104.8	Poor	....	....
Rg-10	34.90	52.40	Poor	....	....
Rg-11	...	87.40	Poor	....	....
Rg-12	34.90	43.65	Fair	Pinhole	Pinhole
Rg-13	...	69.90	Good	Pinhole	Pinhole
Rg-14	34.90	34.90	Good	Pinhole	Pinhole

Table III-D shows the effect of replacing flint by feldspar. In Rg-9 and 10 the ratio of three parts of feldspar to two parts of flint was adopted.

This was the relation of feldspar to flint suggested by Staley[1] for cast iron enamels. In Rg-9 all the flint was replaced by feldspar, and in Rg-10 half of the flint was replaced by feldspar. However, it was noted that replacements in this ratio increased the refractoriness and resulted in a ground coat of poor adherence. The ratio of five to four was employed in replacing the flint by feldspar in Rg-11 and 12, and one to one in Rg-13 and 14. Although these compositions possessed the desired fusibility, there was a decided tendency for the cover enamels applied to the ground to form pinholes. The feldspar, because of its alumina content, would undoubtedly increase the viscosity of the ground coats and might account for the tendency of these compositions high in feldspar to form pinholes.

TABLE III-E

Na_2O–FLINT SERIES

The Effect of Varying Na_2O and Flint in Ground Coats.
Constant Portion Melted 21.57,—13.57 B_2O_3, 8.00 PbO.
Variable Portion Melted 78.43,—Na_2O and Flint

Number	Melted weights		Remarks		
				Texture	
	SiO_2	Na_2O	Adherence	R-1	R-5
Rg-1	69.90	8.53	Good	Good	Good
Rg-22	65.90	12.53	Good	Many pinholes	Many pinholes
Rg-23	61.90	16.53	Good	Many pinholes	Many pinholes

TABLE III-F

B_2O_3–Na_2O SERIES

The Effect of Varying B_2O_3 and Na_2O in Ground Coats.
Constant Portion Melted 77.90,—69.90 Flint, 8.00 PbO.
Variable Portion Melted 22.10,—B_2O_3 and Na_2O

Number	Melted weights		Remarks		
				Texture	
	B_2O_3	Na_2O	Adherence	R-1	R-5
Rg-1	13.57	8.53	Good	Good	Good
Rg-24	17.57	4.53	Good	Few pinholes	Good
Rg-25	9.57	12.53	Good	Good	Few pinholes

Increasing sodium oxide at the expense of flint gave poor results, as the ground coat showed many pinholes (Table III-E). This also resulted in unsatisfactory covers. For this type of ground coat, it was evident that the limit for sodium oxide is between 8.5 and 12.5 per cent.

When boric oxide was replaced by sodium oxide (Table III-F) there was some slight formation of pinholes but fairly good results were obtained with the more refractory covers.

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[1] Bur. of Standards, *Tech. Paper* **142**, p. 22.

In replacing flint by boric oxide, as in Table III-G, little change was noted, the results corresponding very closely to Rg-1. Excessive boric acid, however, tended to slightly increase the number of pinholes.

Excessive addition of raw materials to the mill batch is to be discouraged. Clay and flint as mill additions give the best results although the limits for these are fairly low. Such additions as 15 per cent of clay or 10 per cent each of clay and flint should give most satisfactory results.

Sintering of the ground coats is recommended, since melting of the materials to a glass weakens the resultant ground coat.

TABLE III-G

B_2O_3-FLINT SERIES

The Effect of Varying B_2O_3 and Flint in Ground Coats.
Constant Portion Melted 16.53,—8.53 Na_2O, 8.00 PbO.
Variable Portion Melted 83.47,—B_2O_3 and Flint

Number	Melted weights		Remarks		
				Texture	
	SiO_2	B_2O_3	Adherence	R-1	R-5
Rg-1	69.90	13.57	Good	Good	Good
Rg-26	66.90	17.17	Good	Few Pinholes	Good
Rg-27	62.70	20.77	Good	Few Pinholes	Few Pinholes

TABLE III-H

GROUND COATS OF SERIES III

Melted Compositions

Enamel	Flint	Feldspar	B_2O_3	Na_2O	PbO
Rg-1	69.90	...	13.57	8.53	8.00
Rg-5	73.50	...	13.57	8.53	4.40
Rg-6	66.30	...	13.57	8.53	11.60
Rg-7	62.70	...	13.57	8.53	15.20
Rg-9	...	104.8	13.57	8.53	8.00
Rg-10	34.90	52.4	13.57	8.53	8.00
Rg-11	...	87.40	13.57	8.53	8.00
Rg-12	34.90	44.00	13.57	8.53	8.00
Rg-13	...	69.90	13.57	8.53	8.00
Rg-14	34.90	34.95	13.57	8.53	8.00
Rg-16	69.90	...	21.57	8.53	0.00
Rg-17	69.90	...	17.57	8.53	4.00
Rg-18	69.90	...	9.57	8.53	12.00
Rg-19	69.90	...	13.57	16.53	0.00
Rg-20	69.90	...	13.57	12.53	4.00
Rg-21	69.90	...	13.57	4.53	12.00
Rg-22	65.90	...	13.57	12.53	8.00
Rg-23	61.90	...	13.57	16.53	8.00
Rg-24	69.90	...	17.57	4.53	8.00
Rg-25	69.90	...	9.57	12.53	8.00
Rg-26	66.30	...	17.17	8.53	8.00
Rg-27	62.70	...	20.77	8.53	8.00

TABLE III-I
GROUND COATS OF SERIES III
Batch Compositions

Enamel	Flint	Feldspar	Borax	Sodium nitrate	Soda ash	Red lead	Boric acid
Rg-1	69.90	...	36.96	6.95	..	8.17	...
Rg-5	70.32	...	46.75	..	..	5.01	...
Rg-6	66.30	...	36.96	6.95	..	11.84	...
Rg-7	62.70	...	36.96	6.95	..	15.51	...
Rg-9	...	104.80	36.96	6.95	..	8.17	...
Rg-10	34.90	52.4	36.96	6.95	..	8.17	...
Rg-11	...	87.40	36.96	6.95	..	8.17	...
Rg-12	34.90	44.00	36.96	6.95	..	8.17	...
Rg-13	...	69.90	36.96	6.95	..	8.17	...
Rg-14	34.90	34.90	36.96	6.95	..	8.17	...
Rg-16	69.90	...	36.96	6.95	..	..	14.16
Rg-17	69.90	...	36.96	6.95	..	4.08	7.08
Rg-18	69.90	...	26.07	6.95	3.04	12.24	...
Rg-19	69.90	...	36.96	6.95	13.67	..	...
Rg-20	69.90	...	36.96	6.95	6.84	4.08	...
Rg-21	69.90	...	12.34	6.95	..	12.24	16.00
Rg-22	65.90	...	36.96	6.95	6.84	8.17	...
Rg-23	61.95	...	36.96	6.95	13.67	8.17	...
Rg-24	69.90	...	12.34	6.95	..	8.17	23.06
Rg-25	69.90	...	26.07	6.95	9.88	8.17	...
Rg-26	66.30	...	36.96	6.95	..	8.17	6.37
Rg-27	62.70	...	36.96	6.95	..	8.17	12.75

Excessive additions of any one flux were not desirable, and the best results were obtained when sodium, lead and boric oxides were combined in their proper proportions. Sodium oxide in excess of about 10 per cent, on the basis of melted weights, gave rise to blistering. Boric oxide increased the firing range of the ground coats and was preferable to lead oxide in this respect, although it tended to promote crawling of those ground coats high in boric oxide if they were applied somewhat heavily.

The best ground coats, considering both adherence of the enamel and texture of the cover coats, named in order, were Rg-26, 17, 1, 25, and 18.

Cover Enamels

In view of the results obtained with the cover enamels applied to the various ground coats, it was decided to make a study of the effect of varying composition in cover enamels. In order to bring out the relation of the ground coats and cover coats, the latter were applied to each of three different types of ground coats, namely: a high lead, a medium lead, and a leadless type, or Rg-7, Rg-1, and Rg-16, in the latter all of the lead oxide being replaced by boric oxide. As in the ground coats the replacement of one oxide by another was adopted.

In varying the compositions it was intended to bring out definitely the effect of the various constituents on adherence of the ground coat as well as the relation of the latter to the texture and opacity of the cover enamels. In the study of the ground coats certain defects developed upon the application of cover coats which apparently were not adapted to the particular ground coats; these consisted mainly of black specks, lack of gloss and small incipient pinholes. The black specks had the appearance of dirt or impurities which might have been present in the raw material or which might have been collected in the preparation of the enamel, but this evidently was not the case as the trouble was avoided when the same compositions were used by the dry process. Therefore, it was believed that the specking was due to the longer time required in melting down the covers by the wet process whereby the ground coat became overfired and small particles of it would be dissolved by the cover, resulting in dark specks.

Open pinholes on the surface of the enamels could in most cases be healed over by increasing the length of firing, but it was observed that there still remained small incipient pinholes in the covers and it was impossible to entirely eliminate this defect. The lack of opacity in these cover enamels was caused by solution of the opacifying agents and volatilization of the fluorides. This naturally would be expected to occur when an unreasonable length of time of firing was required to obtain the desired texture as compared with the time for fusing these cover coats when used in the dry process.

It was therefore evident that in order to obtain desirable results it would be necessary to accept several basic compositions and make such substitutions in these as might be expected to develop commercial enamels.

As a basis for this work two types of enamel were chosen, R-1, a medium refractory composition, and R-7, which was comparatively fusible. All cover enamels were smelted in the usual way and the frit was milled with 5 per cent of Johnson-Porter clay, 8 per cent tin oxide, and 45 per cent of water.

Cover R-1 was a rather refractory enamel containing feldspar and quartz, but comparatively low in boric oxide, while R-7 was a more fusible composition, containing feldspar and a high content of boric oxide but no quartz. These compositions were also selected to bring out any relation between ground coats and cover enamels, that is, whether a high boric oxide type could be expected to give better results with a ground coat high in boric oxide.

In Tables IV-E and IV-F and Tables V-F and V-G are shown the melted and batch weights of the compositions studied. These compositions can be grouped in series showing definite variations in composition as shown in Tables IV-A to IV-D for enamels R-8 to 19, based on R-1; and Tables V-A to V-E for enamels R-20 to 35, which are based on R-7.

The compositions based on R-1 have flint, sodium oxide, zinc oxide, and fluorspar constant, since these were present in amounts usually required for satisfactory cover enamels. The flint was not replaced as the refractoriness was varied in the different compositions by replacing the feldspar. Six per cent of zinc oxide in a composition is about the usual amount contained in cast iron cover enamels. An increase of this amount would induce crawling, while decreasing it would lessen the opacity of the enamel. An excessive amount of sodium oxide in covers produced pinholes. Sufficient sodium oxide was reserved in each composition to give about 5 per cent of sodium nitrate in the batch, which is necessary to prevent reduction of the lead compounds. The maximum amount of fluorspar usually added in cast iron covers is about 6 per cent.

TABLE IV-A

(FELDSPAR–B_2O_3) SERIES

The Effect of Varying Feldspar and B_2O_3 in White Cover Enamels.
Constant Portion Melted 53,—12 SiO_2, 8.5 Na_2O, 6 ZnO, 5.5 CaF_2, 5 Cryolite.
Variable Portion Melted 47,—Feldspar and B_2O_3

Enamel	Melted weights		Remarks					
			Rg-1		Rg-7		Rg-16	
	Feld-spar	B_2O_3	Texture	Opacity	Texture	Opacity	Texture	Opacity
R-1	38.0	9.0	Good	Good	Good	Good	Good	Good
R-8	33.0	14.0	Good	Good	Good	Good	Good	Good
R-9	28.0	19.0	Slight crawling	Good ...	Slight crawling	Fair ...	Slight crawling	Good ...
R-10	23.0	24.0	Badly crawled	... ...	Badly crawled	... ...	Badly crawled	... ...

For the reasons stated above, the compounds of sodium oxide, zinc oxide and fluorspar in the compositions based on R-7 were not varied, and since lead oxide and boric oxide were the principal fluxes, it was not thought necessary to vary the amount of barium oxide.

As shown in Table IV-A with boric oxide increased at the expense of feldspar, the results were not very favorable because of the decided tendency of the enamel to crawl or bead. An increase of 5 per cent of boric oxide, over that for R-1, as in R-8, gave results similar to R-1. Although the enamel did not show any tendency to crawl, the incipient pinholes were not entirely avoided. Further increases in boric oxide improved the texture of the enamel but increased the tendency to crawling when applied in a sufficiently heavy coat to give the desired opacity. In cover R-10 the crawling was so increased that the enamel failed to cover the casting properly.

It will be noted that in lowering the refractoriness of the enamels by increasing the boric oxide, the pinholes became fewer when these covers were applied to the more fusible ground coats. The opacity was also improved but some crawling occurred. From these results it was decided that 14 per cent of boric oxide was practically the limit in this particular type of composition in order to produce an enamel of the proper working qualities.

The effect of increasing lead oxide at the expense of feldspar, as noted in Table IV-B, gave some very interesting and instructive results which show more definitely the relation between cover enamels and the different types of ground coats. The data indicated the most suitable cover compositions for each individual ground and appeared to support the assumption made in the preliminary study of this investigation. These compositions on the whole gave very good results. However, it was noted that certain samples were not satisfactory owing to the appearance of black specks and the lack of opacity.

TABLE IV-B

(FELDSPAR–PbO) SERIES

The Effect of Varying Feldspar and PbO in White Cover Enamels.
Constant Portion Melted 46,—12 SiO_2, 9 B_2O_3, 8.5 Na_2O, 6 ZnO, 5.5 CaF_2, 5 Cryolite.
Variable Portion Melted 54,—Feldspar and PbO

Enamel	Melted weights		Remarks					
			Rg-1		Rg-7		Rg-16	
	Feld-spar	PbO	Texture	Opacity	Texture	Opacity	Texture	Opacity
R-1	38.0	16.0	Good	Good	Good	Good	Good	Good
R-11	33.0	21.0	Good	Good	Few pin-holes	Good	Black specks	Good
R-12	28.0	26.0	Good	Good	Few pin-holes	Fair	Black specks	Good
R-13	23.0	31.0	Few pin-holes	Fair	Few pin-holes	Fair	Many pinholes	Fair

It was indicated that varying results could be expected with a particular cover coat, depending on the properties of the ground coat to which it might be applied. It will, therefore, be necessary, in discussing the results obtained with the cover coats, to consider the ground coats which had been used.

The best results obtained with R-11 containing 21 per cent of lead oxide were in connection with Rg-1 ground coat. This combination appeared to give consistent results on a number of trials requiring apparently the same length of time to melt it down. The same cover with Rg-7 and 16 showed a tendency to form pinholes and to develop black specks which was probably due to the ground over-firing before the cover had matured. Cover enamel R-12 containing 26 per cent of lead oxide gave very good results with both Rg-1 and 16, but no improvement over the combination of cover R-1 and ground Rg-1 could be observed.

Covers R-11 or 12 in connection with the use of ground Rg-1 gave practically the same results with the exception of a slight decrease of opacity in R-12. With 31 per cent of lead oxide, as in R-13, pinholes were encountered, this cover giving best results with ground Rg-7. With ground Rg-1 a few pinholes were observed.

The data given above show that the covers should be fusible enough to flow down sufficiently regardless of the composition of the ground coat. An excessive amount of lead oxide in the cover coats used on medium-hard ground coats results in pinholes. It was believed that the fusion point of ground coats and cover enamels should bear a close relation to each other, the best results being obtained when the ground was slightly the more refractory of the two.

TABLE IV-C

B_2O_3–PbO SERIES

The Effect of Varying B_2O_3 and PbO in White Cover Enamels.

Constant Portion Melted 75,—38 Feldspar, 12 SiO_2, 8.5 Na_2O, 6 ZnO, 5.5 CaF, 5 Cryolite.

Variable Portion Melted, 25,—B_2O_3 and PbO

Enamel	Melted weights		Remarks					
			Rg-1		Rg-7		Rg-16	
	B_2O_3	PbO	Texture	Opacity	Texture	Opacity	Texture	Opacity
R-14	4.0	21.0	Good	Good	Good	Good	Good	Good
R-1	9.0	16.0	Good	Good	Good	Good	Good	Good
R-15	14.0	11.0	Good	Good	Good	Good	Black specks	Good
R-16	19.0	6.0	Slight crawling	Good	Slight crawling	Good	Slight crawling	Good
R-17	24.0	1.0	Crawled	Good	Crawled	Good	Crawled	Good

The results obtained in replacing lead oxide by boric oxide (Table IV-C) were not as satisfactory as in the previous series. This variation maintained the refractoriness of the composition practically constant. The results showed clearly that neither of the two fluxes could be eliminated in the composition as each gave certain necessary fusible properties in the enamel. In R-14, with 5 per cent of boric oxide replaced by lead oxide, little difference in opacity was noted between it and R-1. This enamel had a good texture and consistent results were obtained with a number of samples. It was apparent that the effect of replacing boric oxide with lead oxide was more satisfactory than that of replacing feldspar by lead oxide as the elasticity of the enamel was increased, permitting the application of a heavier coat. With the increase of boric oxide, crawling increased. In R-15, where 5 per cent of lead oxide was replaced by boric oxide, good results were obtained with Rg-1, the enamel having good texture and opacity. This change slightly increased the refractoriness of the cover and offers further evidence that the melting points of both compositions should be about the same, because R-15 with both Rg-7 and Rg-16 had a decided tendency to produce black specks. Very poor results were obtained with both R-16 and R-17 in connection with the use of the three different ground coats. Crawling was increased in proportion to the increase of boric oxide. In order to prevent crawling with these enamels it would be necessary to apply it so thin that the opacity would be lacking.

As shown in Table IV-D, where feldspar was replaced by cryolite, the results obtained were very satisfactory considering both texture and opacity. The advantage of replacing feldspar by cryolite over the replacement of feldspar by lead oxide was the increase of opacity as well as the fusibility of the composition. Replacing 5 per cent of the feldspar by cryolite gave very good results with the three different types of ground coats, but when 10 per cent of feldspar was replaced by cryolite the results were not so favorable, pinholes being apparent in the covers used with both Rg-1 and Rg-16. Aside from this feature, it was noted that this enamel had a slight tendency to crawl when applied rather heavily. R-18a, with 7.5 per cent of feldspar replaced by cryolite, gave results similar to those of R-18, while in R-19a, with 12.5 per cent of feldspar replaced by cryolite, the same trouble was incurred as in R-19 with a further increase of cryolite to 15 per cent.

TABLE IV-D

FELDSPAR–CRYOLITE SERIES

The Effect of Varying Feldspar and Cryolite in White Cover Enamels.
Constant Portion Melted 57,—12 SiO_2, 9 B_2O_3, 8.5 Na_2O, 16 PbO, 6 ZnO, 5.5 CaF_2.
Variable Portion Melted 43,—Feldspar and Cryolite

Enamel	Melted weights		Remarks					
			Rg-1		Rg-7		Rg-16	
	Feld-spar	Cryo-lite	Texture	Opacity	Texture	Opacity	Texture	Opacity
R-1	38.0	5.0	Good	Good	Good	Good	Good	Good
R-18a	35.5	7.5	Good	Good	Good	Good	Good	Good
R-18	33.0	10.0	Good	Very good	Good	Very good	Good	Good
R-19a	30.5	12.5	Good	Very good	Good	Very good	Black specks	Good
R-19	28.0	15.0	Good	Very good	Good	Very good	Black specks	Good

The above results indicate that cryolite should not exceed 10 per cent to give the most satisfactory results in cover enamels of this type.

When using R-7 as a basic composition the results obtained by the various substitutions were not as satisfactory in their entirety as those in the previous series because of the lack of opacity. However, several good compositions were developed, and the work shows definitely the different effects on cover enamels of this type when the same substitutions are made as in the previous series. As the basic composition R-7 was

TABLE IV-E

WHITE COVER ENAMELS OF SERIES IV

Melted Compositions

Enamel	Feldspar	Flint	B_2O_3	Na_2O	PbO	ZnO	CaF_2	Cryolite
R-1	38.0	12.0	9.0	8.5	16.0	6.0	5.5	5.0
R-8	33.0	12.0	14.0	8.5	16.0	6.0	5.5	5.0
R-9	28.0	12.0	19.0	8.5	16.0	6.0	5.5	5.0
R-10	23.0	12.0	24.0	8.5	16.0	6.0	5.5	5.0
R-11	33.0	12.0	9.0	8.5	21.0	6.0	5.5	5.0
R-12	28.0	12.0	9.0	8.5	26.0	6.0	5.5	5.0
R-13	23.0	12.0	9.0	8.5	31.0	6.0	5.5	5.0
R-14	38.0	12.0	4.0	8.5	21.0	6.0	5.5	5.0
R-15	38.0	12.0	14.0	8.5	11.0	6.0	5.5	5.0
R-16	38.0	12.0	19.0	8.5	6.0	6.0	5.5	5.0
R-17	38.0	12.0	24.0	8.5	1.0	6.0	5.5	5.0
R-18	33.0	12.0	9.0	8.5	16.0	6.0	5.5	10.0
R-19	28.0	12.0	9.0	8.5	16.0	6.0	5.5	15.0
R-18a	35.0	12.0	9.0	8.5	16.0	6.0	5.5	7.5
R-19a	30.5	12.0	9.0	8.5	16.0	6.0	5.5	12.5

TABLE IV-F

WHITE COVER ENAMELS OF SERIES IV

Batch Compositions

Enamel	Feldspar	Flint	Borax	Sodium nitrate	Soda ash	Red lead	Zinc oxide	Fluorspar	Cryolite	Boric acid
R-1	38.0	12.0	24.52	6.20	3.86	16.42	6.0	5.5	5.0	...
R-8	33.0	12.0	38.14	6.35	..	16.42	6.0	5.5	5.0	...
R-9	28.0	12.0	38.14	6.35	..	16.42	6.0	5.5	5.0	8.85
R-10	23.0	12.0	38.14	6.35	..	16.42	6.0	5.5	5.0	17.70
R-11	33.0	12.0	24.52	6.20	3.86	21.60	6.0	5.5	5.0	...
R-12	28.0	12.0	24.52	6.20	3.86	26.70	6.0	5.5	5.0	...
R-13	23.0	12.0	24.52	6.20	3.86	31.80	6.0	5.5	5.0	...
R-14	38.0	12.0	10.90	6.20	7.70	21.60	6.0	5.5	5.0	...
R-15	38.0	12.0	38.14	6.35	..	11.30	6.0	5.5	5.0	...
R-16	38.0	12.0	38.14	6.35	..	6.20	6.0	5.5	5.0	8.85
R-17	38.0	12.0	38.14	6.35	..	1.03	6.0	5.5	5.0	17.75
R-18	33.0	12.0	38.14	6.20	3.86	16.42	6.0	5.5	5.0	...
R-19	28.0	12.0	24.52	6.20	3.86	16.42	6.0	5.5	5.0	...
R-18a	35.5	12.0	24.52	6.20	3.86	16.42	6.0	5.5	5.0	...
R-19a	30.5	12.0	24.52	6.20	3.86	16.42	6.0	5.5	5.0	...

considerably more fusible than R-1, the results with enamels in which the feldspar content remained constant or was increased, proved more favorable than where feldspar was decreased below that percentage in the base enamel.

In R-20, increasing the feldspar 5 per cent at the expense of boric oxide, as in Table V-A, good results were obtained with grounds Rg-1 and 7 although the opacity was not exceptionally good in either case. There was a slight improvement over R-7. Increasing the feldspar 10 per cent at the expense of the boric oxide gave good results with the three different types of ground coats. The opacity was not improved over R-20 and in certain samples there was a tendency to form black specks, the latter fact indicating that the cover was too refractory for the different ground coats. Increasing the boric oxide 5 per cent at the expense of feldspar, as in cover R-22, affected the properties of the composition as might be expected from the results obtained from R-20 and R-21. This cover used with Rg-1 and 16 had poor texture and opacity. In both cases

TABLE V-A

FELDSPAR–B_2O_3 SERIES

The Effect of Varying Feldspar and B_2O_3 in White Cover Enamels.
Constant Portion Melted 40,—11 Na_2O, 15 PbO, 5 ZnO, 3.5 BaO, 5.5 CaF_2.
Variable Portion Melted 60,—Feldspar and B_2O_3

Enamel	Melted weights		Remarks					
	Feldspar	B_2O_3	Rg-1		Rg-7		Rg-16	
			Texture	Opacity	Texture	Opacity	Texture	Opacity
R-21	50.0	10.0	Good	Fair	Good	Fair	Good	Fair
R-20	45.0	15.0	Good	Fair	Good	Fair	Good	Fair
R-7	40.0	20.0	Good	Fair	Good	Fair	Good	Good
R-22	35.0	25.0	Black specks	Poor	Good	Fair	Black specks	Poor

TABLE V-B

FELDSPAR–PbO SERIES

The Effect of Varying Feldspar and PbO in White Cover Enamels.
Constant Portion Melted 45,—20 B_2O_3, 11 Na_2O, 5 ZnO, 3.5 BaO, 5.5 CaF_2.
Variable Portion Melted 55,—Feldspar and PbO

Enamel	Melted weights		Remarks					
	Feldspar	PbO	Rg-1		Rg-7		Rg-16	
			Texture	Opacity	Texture	Opacity	Texture	Opacity
R-24	50.0	5.0	Good	Fair	Good	Fair	Good	Fair
R-23	45.0	10.0	Good	Fair	Good	Fair	Good	Fair
R-7	40.0	15.0	Good	Fair	Good	Fair	Good	Fair
R-25	35.0	20.0	Good	Poor	Good	Poor	Good	Poor
R-26	30.0	25.0	Good	Poor	Good	Poor	Good	Poor
R-27	25.0	30.0	Good	Poor	Good	Poor	Good	Poor

many black specks were apparent. When used with Rg-7 the texture was free from black specks but the opacity was not improved. Apparently the best combination obtained from this study was R-20 used in connection with ground Rg-1.

In Table V-B is shown a series with lead oxide replaced by feldspar and feldspar replaced by lead oxide. The results obtained were fairly satisfactory as to texture, but opacity was lacking throughout the whole series. With these various substitutions Rg-1 appeared to be the most suitable ground coat. Increasing the lead oxide bettered the texture with covers applied on ground Rg-1; however, a decrease of opacity was noticed as the lead oxide was increased.

TABLE V-C

PbO–B_2O_3 SERIES

The Effect of Varying PbO and B_2O_3 in White Cover Enamels.
Constant Portion Melted 65,—40 Feldspar, 11 Na_2O, 5 ZnO, 3.5 BaO, 5.5 CaF_2.
Variable Portion Melted 35,—PbO and B_2O^3

Enamel	Melted weights		Remarks					
	B_2O_3	PbO	Rg-1		Rg-7		Rg-16	
			Texture	Opacity	Texture	Opacity	Texture	Opacity
R-28	25.0	10.0	Good	Good	Good	Good	Good	Good
R-7	20.0	15.0	Good	Fair	Good	Fair	Good	Good
R-29	15.0	20.0	Good	Fair	Good	Fair	Black specks	Good
R-30	10.0	25.0	Good	Fair	Few pinholes	Fair	Few pinholes	Fair
R-31	5.0	30.0	Many pinholes	Fair	Many pinholes	Fair	Many pinholes	Fair

Replacing 5 per cent of lead oxide with feldspar gave an enamel having good texture with either of the three types of grounds, but in each case opacity was lacking. Increasing feldspar 10 per cent at the expense of lead oxide further increased the opacity and there was considerable formation of pinholes when these cover enamels were used over the softer grounds.

Replacing the feldspar by lead oxide gave rather poor results with Rg-7 and 16, pinholes being formed with each step and the opacity decreasing proportionally with the increase of lead oxide. However, it was noted that the same composition used with Rg-1 gave enamels with fairly good texture.

From the data given above it was decided that a high content of lead oxide decreased the opacity of the enamel. Cover R-23 when used with ground Rg-1 apparently gave the best results of any enamel in this series.

Replacing lead oxide by boric oxide (Table V-C) produced enamels having more desirable properties than those obtained in the previous series based on Cover R-7. It was noted that the opacity could be controlled more successfully by varying the proportion of the fluxes.

The most satisfactory composition developed in this series was R-28. The properties of this enamel were such that good results were obtained with the three different types of grounds.

Cover R-28 contains 25 per cent of boric oxide. This amount is unusually high, but for this particular type of enamel a high boric oxide content produced the most beneficial results. However, it was noted that more care was required in the manipulation, as a composition of this kind is more liable to crawl than the lead type. Increasing the lead oxide at the expense of boric oxide, as in covers R-29, 30 and 31, produced enamels with lower viscosity, but with many of the samples pinholes and black specks were formed, these features being noticeable when either of the three types of ground coats was used. The opacity was decidedly decreased with the increase of lead oxide and with increase of 15 per cent the enamel approached a clear glass.

Table V-D

Feldspar–Cryolite Series

The Effect of Varying Feldspar and Cryolite in White Cover Enamels.
Constant Portion Melted 60,—20 B_2O_3, 11 Na_2O, 15 PbO, 5 ZnO, 3.5 BaO, 5.5 CaF_2.
Variable Portion Melted 40,—Feldspar and Cryolite

Enamel	Melted weights		Remarks					
			Rg-1		Rg-7		Rg-16	
	Feldspar	Cryolite	Texture	Opacity	Texture	Opacity	Texture	Opacity
R-7	40.0	...	Good	Fair	Good	Fair	Good	Good
R-32	35.0	5.0	Fine pinholes	Fair	Black specks	Poor	Good	Poor
R-33	30.0	10.0	Crawled Few pinholes	Poor	Crawled Many pinholes	Poor	Crawled Black specks	Poor

Table V-E

B_2O_3–Cryolite Series

The Effect of Varying B_2O_3 and Cryolite in White Cover Enamels.
Constant Portion Melted 80,—40 Feldspar, 11 Na_2O, 15 PbO, 5 ZnO, 3.5 BaO, 5.5 CaF_2.
Variable Portion Melted 20,—B_2O_3 and Cryolite

Enamel	Melted weights		Remarks					
			Rg-1		Rg-7		Rg-16	
	B_2O_3	Cryolite	Texture	Opacity	Texture	Opacity	Texture	Opacity
R-7	20.0	..	Good	Fair	Good	Fair	Good	Good
R-34	15.0	5.0	Good	Fair	Crawled	Fair	Few pinholes	Fair
R-35	10.0	10.0	Many pinholes	Poor	Few pinholes	Poor	Few pinholes	Poor

The replacement of feldspar by cryolite (Table V-D) in this type of enamel did not prove very successful. The most serious objection was crawling, while the texture and opacity were not improved to any noticeable extent.

The fact that cryolite had vastly different effects in the two different types of basic enamels shows rather definitely that a broad statement cannot be made as to its effect in different types of compositions.

The lack of opacity in these enamels containing cryolite may be due to the fusibility of the enamel, probably allowing easy volatilization of the fluorine and solution of the opacifying agents.

It was also noted that in increasing cryolite at the expense of feldspar and boric oxide, crawling of the enamel occurred.

The replacement of boric oxide by cryolite (Table V-E) as in R-34 and 35, gave results which were very similar to those obtained with R-32 and 33. These enamels had a decided tendency to crawl and the texture was not satisfactory when either composition was used with the three different types of ground coats.

It will be noted that vastly different results were obtained varying by the same constituents in the composition of R-1 and R-7. The most appreciable difference was noted when the effect of cryolite in these compositions was studied. The same amount of boric oxide in the two compositions gave decidedly different results. It is evident that the limit for boric oxide is higher in the case of the more fusible enamels. This may

TABLE V-F

WHITE COVER ENAMELS OF SERIES V

Melted Compositions

Enamel	Feldspar	B_2O_3	Na_2O	PbO	ZnO	BaO	CaF_2	Cryolite
R-7	40.0	20.0	11.0	15.0	5.0	3.5	5.5	..
R-20	45.0	15.0	11.0	15.0	5.0	3.5	5.5	..
R-21	50.0	10.0	11.0	15.0	5.0	3.5	5.5	..
R-22	35.0	25.0	11.0	15.0	5.0	3.5	5.5	..
R-23	45.0	20.0	11.0	10.0	5.0	3.5	5.5	..
R-24	50.0	20.0	11.0	5.0	5.0	3.5	5.5	..
R-25	35.0	20.0	11.0	20.0	5.0	3.5	5.5	..
R-26	30.0	20.0	11.0	25.0	5.0	3.5	5.5	..
R-27	25.0	20.0	11.0	30.0	5.0	3.5	5.5	..
R-28	40.0	25.0	11.0	10.0	5.0	3.5	5.5	..
R-29	40.0	15.0	11.0	20.0	5.0	3.5	5.5	..
R-30	40.0	10.0	11.0	25.0	5.0	3.5	5.5	..
R-31	40.0	5.0	11.0	30.0	5.0	3.5	5.5	..
R-32	35.0	20.0	11.0	15.0	5.0	3.5	5.5	5.0
R-33	30.0	20.0	11.0	15.0	5.0	3.5	5.5	10.0
R-34	40.0	15.0	11.0	15.0	5.0	3.5	5.5	5.0
R-35	40.0	10.0	11.0	15.0	5.0	3.5	5.5	10.0

TABLE V-G
WHITE COVER ENAMELS OF SERIES V
Batch Compositions

Enamel	Feldspar	Borax	Sodium nitrate	Soda ash	Red lead	Zinc oxide	Barium carb.	Fluorspar	Cryolite	Boric acid
R-7	40.0	24.52	5.95	..	15.40	5.0	4.5	5.5	..	..
R-20	45.0	41.0	5.95	3.73	15.4	5.0	4.5	5.5	..	..
R-21	50.0	27.3	5.95	7.55	15.4	5.0	4.5	5.5	..	8.85
R-22	35.0	54.5	5.95	..	15.4	5.0	4.5	5.5	..	..
R-23	45.0	54.5	5.95	..	10.3	5.0	4.5	5.5	..	..
R-24	50.0	54.5	5.95	..	5.15	5.0	4.5	5.5	..	..
R-25	35.0	54.5	5.95	..	20.6	5.0	4.5	5.5	..	..
R-26	30.0	54.5	5.95	..	25.7	5.0	4.5	5.5	..	..
R-27	25.0	54.5	5.95	..	30.9	5.0	4.5	5.5	..	..
R-28	50.0	54.5	5.95	..	10.3	5.0	4.5	5.5	..	8.85
R-29	40.0	41.0	5.95	3.73	20.6	5.0	4.5	5.5	..	..
R-30	40.0	27.3	5.95	7.55	25.7	5.0	4.5	5.5	..	..
R-31	40.0	13.6	5.95	11.30	30.9	5.0	4.5	5.5	..	..
R-32	35.0	54.5	5.95	..	15.4	5.0	4.5	5.5	5.0	..
R-33	30.0	54.5	5.95	..	15.4	5.0	4.5	5.5	10.0	..
R-34	40.0	41.0	5.95	3.73	15.4	5.0	4.5	5.5	5.0	..
R-35	40.0	27.3	5.95	7.55	15.4	5.0	4.5	5.5	10.0	..

be due to the fact that the refractory enamels are comparatively viscous and this property is emphasized by the additions of such a substance as boric oxide.

The different effects in the two compositions show rather definitely that the effects of boric oxide and cryolite can be stated only in relation to a definite composition.

Summary

The primary purpose of this investigation has been to learn the effect of varying composition and treatment on wet process enamels. A number of satisfactory enamels have been developed and information has been gained regarding the technic of this type of enameling. While consideration must be given to the comparative refractoriness of the ground and cover coats, the following compositions may be mentioned as having given very satisfactory results: Ground coats Rg-26, 17, 1, 25, and 18, and cover coats R-14, 11, 28, 1, and 18. The laboratory results for the more promising enamels have been checked on a factory basis, and, taking into consideration the variations in furnace and factory conditions, the conclusions drawn from the laboratory work have been confirmed.

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WASHINGTON, D. C.

Discussion

MR. SWEELY:—I would like to ask, if you mean crawling of the enamel before fusion or afterwards; when you first put it into the furnace?

MR. DANIELSON:—When it first goes in the furnace there is a sort of cracking of the enamel, it then peels back leaving the metal exposed. An enamel that would so crack and crawl would not be a practical ground coat to use, or in the case of cover coat it would not be satisfactory for commercial purposes.

MR. WEISTER:—How fast did you dry that enamel?

MR. DANIELSON:—That is a very important thing in connection with the use of wet process enameling. It is very important that the cover coats dry very thoroughly before they are used and dried slowly. Samples were placed in a drier at about ninety degrees and probably dried in about an hour's time, thoroughly; and for safety we then left those in an hour longer. Unless the cover compositions are dried thoroughly there would be cracking and crawling of the enamel.

The results we have obtained in that connection have also been verified in commercial practice, where wet process enamels are used. It is absolutely necessary to dry slowly and dry carefully in all cases in order to avoid cracking.

MR. MALINOVSKY:—Is not the same true also of steel enamels?

MR. DANIELSON:—It is true with sheet steel enamel, but wet process enamels on cast iron must be dried somewhat slower and much more thoroughly. One explanation of that may be that the cast iron is somewhat more porous, and, also, the moisture is retained longer in these than in sheet steel coated with a rather glassy ground coat.

THE INFLUENCE OF HEAT ON THE MICROSCOPIC PROPERTIES OF SILICA IN ITS DIFFERENT MINERAL FORMS[1]

By J. T. Robson

ABSTRACT

A study is made of the effect of heat at cone 13 and cone 14 on the index of refraction of the four common mineral forms of silica used in the ceramic industries. These mineral forms are sand, quartz, chalcedony and French flint. The effect of these mineral forms on the index of refraction of porcelain bodies fired to cone 13 and cone 14 is also given.

The inversions of silica are recognized as a source of weakness in any ceramic body into which it is introduced. The inversion temperatures for quartz have been determined with great care and are as follows:

Inversion	Temperature	Remarks[2]
A quartz–B quartz	575° C	Rapid, reversible
B quartz–B_2 tridymite	870°±10°	Very sluggish, reversible
B tridymite–B cristobalite	1470°±10°	Very sluggish, reversible

The different mineral forms of silica used in the ceramic industries make it of special interest to know their difference in behavior resulting from heat treatment. At the present time there are four different mineral forms of silica on the market. These are as follows:

(1) Common Potters Flint, a silica sand obtained by washing a sand rock and pulverizing the product.

(2) Rock Quartz, a massive quartz rock, called sugar quartz, which occurs as intrusions in pegmatites and granites. This rock is calcined at about 1000°C which weakens its structure and it is then pulverized.

(3) French Flint, a nodular form of silica, which occurs as pebbles along the Atlantic coast of Europe and Greenland. These pebbles are probably segregated silica from the slimes of the ocean bottom which have worked up to the shore level. The pebbles are calcined at about 1000°C which renders them friable and then easily pulverized.

(4) Chalcedony, a massive but rather easily crushed rock, occurring in considerable quantity as lens or pocket deposits in southwestern Illinois. This is crushed and pulverized.

These four mineral forms of silica were studied as they are ordinarily furnished to the ceramic industries and also after being heated to temperatures of cone 13 (1390°C) and cone 14 (1410°C). These four mineral forms of silica were also studied in porcelain bodies fired at cones 13 and 14.

Method of Procedure.—The bodies together with samples of the silicas alone were placed in an 8 inch by 8 inch circular sagger, covered and placed inside a larger sagger and burned in the load test furnace (compressed air-gas) to cone 13 down inside the small sagger. The time required for this burn was 4½ hours.

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[1] Presented at the St. Louis Meeting, Feb. 28, 1922.

[2] "The Ternary System $CaO-Al_2O_3-SiO_2$," Rankin & Wright, *Am. J. Sci.*, **39**, 4 (1915).

Another burn to cone 14 down inside the sagger was made using similar porcelain bodies and the silicas alone. The time required for this burn was $4^1/_4$ hours.

The porcelain body used had the following composition:

Canadian Feldspar	20%
Florida Kaolin	45%
Silica	35%
	100%

These bodies were made into circular discs about 3 inches in diameter by about ½ inch thick.

The body samples were pulverized to an impalpable powder in an agate mortar. The silt was removed by decantation with water and the residue examined in order to show as distinctly as possible the free silica grains not enveloped with the conglomerate body.

A 4 mm. objective was used in this work. This was especially necessary in examining the chalcedony which is micro-crystalline.

Results

TABLE I

SCREEN ANALYSIS OF DIFFERENT FORMS OF SILICA

Material	Cumulative percentage residue			
	100 m.	150 m.	200 m.	300 m.
Sand	0.35	0.35	1.97	4.57
Quartz	0.70	2.39	11.41	23.29
Chalcedony	0.06	0.72	1.27	1.68
French Flint	0.26	1.74	4.27	8.56

TABLE II

EFFECT OF HEAT ON INDEX OF REFRACTION OF DIFFERENT FORMS OF SILICA

Material	Index before heating	Index after heating to cone 13	Index after heating to cone 14
Sand	1.545	1.545	1.509
Quartz	1.545	1.545	1.517
Chalcedony	1.540	1.527	1.495
French Flint	1.527	1.487	1.487

TABLE III

INDEX OF REFRACTION OF PORCELAIN BODIES MADE WITH DIFFERENT FORMS OF SILICA

Material	Index of body fired to cone 13	Index of body fired to cone 14
Sand	1.522	1.508
Quartz	1.523	1.500
Chalcedony	1.512	1.502
French Flint	1.518	1.505

Comments.—Table II shows that both the sand and quartz before heating have an index of refraction of 1.545 which practically corresponds to 1.54425, the value given for SiO_2 by Winchell.[1]

No effect is noticed in the case of either sand or quartz on the index at cone 13, about 1390°C, but at cone 14, about 1410°C, a decided drop has taken place in the indices of both substances, showing that above cone 13 both sand and quartz tend to transform into cristobalite which has an index of refraction of 1.487.[2]

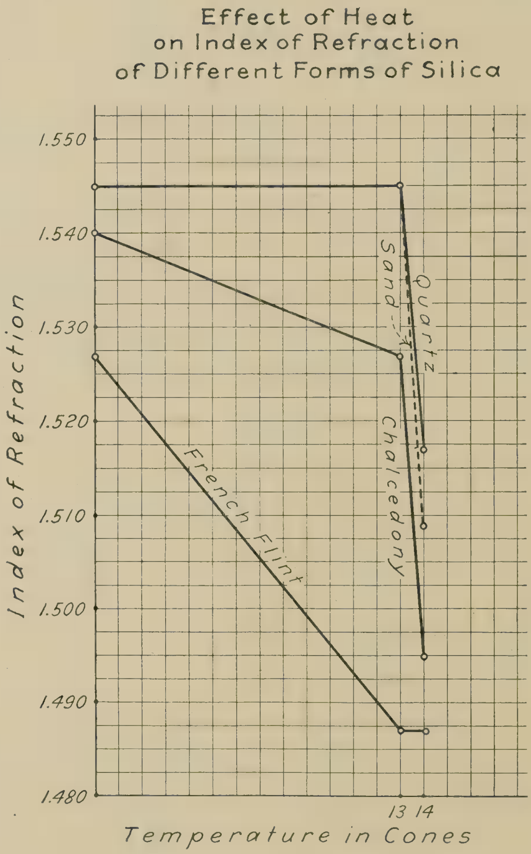

FIG. 1.

The French flint before heating has an index of 1.527 which is lower than that of ordinary quartz (1.545). This is due no doubt to the fact that before French flint is ground the pebbles are calcined at about 1000°C (cone 07).

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[1] "Elements of Optical Mineralogy," p. 341.

[2] Rankin & Wright, *Am. J. Sci.*, 39, 4 (1915).

At cone 13 this French flint changed entirely to cristobalite, as shown by the index 1.487. This index remained unchanged at cone 14. Since the lowest burn made was at cone 13, it is not known whether or not French flint is entirely inverted into cristobalite below cone 13.

Before heating, the index of chalcedony was 1.540, which is 0.005 below that of ordinary quartz. At cone 13, the index fell to 1.527, which is the same as that found for the French flint as received. At cone 14 the index is 1.495, which is but 0.008 greater than that for cristobalite, showing that at cone 14 the chalcedony has nearly inverted into pure cristobalite.

In general, it is to be noted that heat has a very similar effect on the index of refraction of both flint and quartz. This is shown by the attached curve A which also shows the effect of heat on the index of refraction of chalcedony and French flint.

It was found impossible to obtain the correct index of refraction of the silicas in the porcelain aggregates because the crystal could not be absolutely segregated and upon raising the body tube of the microscope the Becke line would go in on one side but out on the other.

With the bodies containing flint, quartz and French flint, many free silica crystals could be observed when the bodies were very finely ground. With the body containing chalcedony, a few white opaque crystals could be observed under crossed nicols, the same as observed with chalcedony alone under crossed nicols, tending to show that some uncombined chalcedony was present. This chalcedony body appeared to be very fine grained and not of large crystalline structure as the other three bodies.

Table III shows that the index of the various conglomerate bodies did not differ to a very great extent. Considerable difficulty was experienced in obtaining the index of these bodies because of lack of a clear definite line of light.

The quartz in the raw state, although white, was slightly darker than the other silicas. This difference in color was more intensified after heating, the quartz having a very pale straw color, whereas the other materials were extremely white. A similar effect on wetting the silicas was noted. The quartz possessed the darkest color, the French flint also had a faint dark color when wet. After the silt was decanted off, as described in the procedure, the difference in color was not nearly so intense, due probably to the fact that traces of clay were present which would be included in the silt.

Table I shows that the quartz used in this study was much coarser than the other silicas used and that the chalcedony was much finer than the others.

Since this paper was prepared a communication has been received from Dr. R. Rieke of Charlottenberg, Germany, to whom a portion of the same samples had been sent. Dr. Rieke studied the speed of transformation into cristobalite by burning the samples to 1430°C and noting the change in their specific gravity.[1]

He obtained the following results:

TABLE IV

Material	Specific gravity before burning	Specific gravity after burning to 1430°C
Sand............	2.67	2.49
Quartz...........	2.66	2.49
Chalcedony.......	2.66	2.32
French Flint......	2.58	2.28

Cristobalite has a specific gravity of 2.32.

This work in agreement with the writer's work tends to show that French flint and chalcedony both transform into cristobalite before sand and quartz, which appear to alter about the same.

Table IV shows that at 1430°C chalcedony had entirely transformed into cristobalite and since, according to Table II, it had not inverted at 1410°C, the temperature of 1430°C is probably very close to the inversion temperature of chalcedony into cristobalite.

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[1] *Berichte der Deutschen Keramischen Gesellschaft,* **2,** 169 (1921).

TALC AS A FLUX FOR HIGH TENSION INSULATOR PORCELAINS[1]

By Robert Twells, Jr.[2]

ABSTRACT

MgO has some possibilities as a partial or total flux in high tension insulator porcelains. To be practical for this purpose it must be introduced into the body through some cheap material which will not make a large percentage of calcine necessary.

Talc seems to fulfill these requirements better than other sources of MgO more commonly used.

A typical high tension insulator body of the general formula 0.21 K_2O, 1.0 Al_2O_3, 4.45 SiO_2 was used as a standard. The experimental work consisted chiefly in the partial replacement of the K_2O by MgO, the RO being varied between 0.14 and 0.30 equivalents. Talc was used as the source of MgO.

The bodies were fired to temperatures ranging between cones 9 and 11 and were tested in most cases only for absorption and transverse strength.

The results at cone 10½ indicate (1) a small addition of talc greatly decreases the percentage of feldspar necessary for vitrification, (2) additional small amounts of talc have much less effect than the first small addition, (3) about 0.16 equivalents of Ro are needed for vitrification at this temperature when small percentages of talc are used. This corresponds to about 15 to 22.5% of feldspar and about 2.5% to 0.75% of talc, (4) in the properly vitrified bodies the addition of the MgO at the expense of the K_2O, within the limits tested, tends to increase the transverse strength. Vitrified bodies of this general type show little improvement, if any, over regular triaxial porcelains. The writer recommends as the next logical step a trial of the effect of the replacement of feldspar entirely or almost entirely by talc and the use of higher temperatures to obtain vitrification.

Introduction

In the literature of the American Ceramic Society there are many articles on the use of MgO in ceramic bodies. These articles cover several methods of introducing this oxide into bodies intended for different purposes. The sources of the MgO used were magnesia, fused magnesia, magnesite, dolomite, talc, or a calcine. The bodies reported may be classified on a basis of vitrification as vitreous, semi-vitreous and very porous. One of the first requirements of a high tension insulator porcelain is that it be as nearly non-porous as possible. As Barringer[3] has pointed out, experiments with improperly vitrified bodies give little information as to the effect of MgO in this type of porcelain. MgO in a porous body may have a certain effect; for example, giving good resistance to heat changes, and yet fail to give good results in a vitreous body. It is possible however, to pick several points from our literature which will indicate in a general way the effect of this oxide as an ingredient in high tension insulator porcelains.

[1] White Wares Division, St. Louis Meeting, Feb. 28, 1922.

[2] Most of the experimental work described in this article was done jointly with Mr. C. C. Lin, Research Laboratories, General Electric Company, Schenectady, New York.

[3] L. E. Barringer, *Trans. Amer. Ceram. Soc.*, 6, 86 (1904).

1. MgO, in small amounts, lowers the maturing point of a triaxial body, but does not shorten its vitrification range as does CaO.[1]

2. In triaxial bodies not fired to vitrification, the first small additions of MgO lower the porosity most decidedly.[2] The rate decreases as the amount is increased.

3. Vitreous bodies containing MgO tend to be resistant to heat changes.[3]

4. MgO greatly accelerates the formation of sillimanite.[4]

5. The hot dielectric strength of a vitrified body composed only of MgO, Al_2O_3, and SiO_2 is much higher than that of a feldspar porcelain.[5]

6. The minimum temperature at which fluxing action would be expected in a body composed only of MgO, Al_2O_3, and SiO_2 would be cone 12 down, since this was reported by Watts as being the eutectic temperature of these three oxides.[6]

7. Watts reported highly translucent bodies at cone 13 composed only of MgO, Al_2O_3, and SiO_2.[7]

A study of these general effects of MgO in a vitreous body impresses one with its possibilities as a partial or total substitute for the K_2O in a feldspar high tension insulator porcelain. This seems especially true in view of the recent work of the Bureau of Standards on spark plug porcelain composed only of MgO, Al_2O_3, and SiO_2.[8]

As Klinefelter[9] recently pointed out, this general type of porcelain might also be superior to a good feldspar porcelain for high tension insulator use. But this remains to be proven. Feldspar porcelain insulators have been used successfully for many years under a wide variety of conditions. Feldspar, also, has the desirable properties of being simple to introduce, safe in fluxing action, and giving a relatively low maturing point to a body. On the other hand, as Klinefelter[10] also pointed out, the voltages used on high tension transmission lines are gradually being increased and there is a corresponding demand for a very superior electrical porcelain. A high tension insulator porcelain radically superior in every property to those now available can hardly be expected by the use of only feldspar, flint, and clay. If one property is improved by changing the relative percentages of these ingredients other properties will be less satisfactory. The best "all-around" triaxial bodies are those which have been developed by compromising between the desired properties.[1]

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[1] F. H. Riddle and W. W. McDanel, *Jour. Amer. Ceram. Soc.*, **1**, 606 (1918).

[2] H. Hope, *Trans. Amer. Ceram. Soc.*, **11**, 494 (1909).

[3] E. T. Montgomery, *Ibid.*, **15**, 606 (1913).

[4] A. V. Bleininger and F. H. Riddle, *Jour. Amer. Ceram. Soc.*, **2**, 564 (1919).

[5] *Ibid.*

[6] A. S. Watts, *Trans. Amer. Ceram. Soc.*, **19**, 453 (1917).

[7] *Ibid.*

[8] A. V. Bleininger and F. H. Riddle, *Ibid.*

[9] T. A. Klinefelter, *The New Jersey Ceramist*, **1**, 251–67 (1921).

[10] T. A. Klinefelter, *Ibid.*

It is, then, desirable to consider whether improvement can be attained by the total or partial replacement of the flint and feldspar by other materials. The spark plug porcelains developed by the Bureau of Standards would seem logical types towards which to experiment.

As a flux in these porcelains a calcine of the general formula X MgO Al_2O_3 Y SiO_2 is recommended. A calcine is desirable to eliminate the excessive shrinkage which would otherwise be caused by the high clay content necessary in a body in which feldspar is replaced by magnesite. This is especially true if the flint content of the body is also reduced. A body containing such a calcine could hardly be used for high tension insulators owing to the cost of mixing, pressing, pugging, firing, and grinding 50 to 60% of the materials before they could be used in the body. Unless it had extremely good properties it would be cheaper to use several strings of feldspar porcelain insulators rather than one of this type.

The commercial possibility of the use of MgO as a partial or total flux for high tension insulator porcelains depends largely on the method of introducing the MgO. The source of the MgO must not only be cheap, but it must also be in such a form as to eliminate the necessity for a large percentage of calcine. Fused MgO would be too expensive. Barringer[2] has shown some of the objections to the direct introduction of magnesia into a body. Dolomite introduces too much CaO and gives off an objectionable amount of gases in firing. Magnesite is expensive. It also gives off a large amount of gases in firing and tends to give an excessive shrinkage in a body. In common with the other possible sources mentioned, it would be necessary to calcine a large percentage of the raw materials. The most important source of MgO left to consider is talc.

Parmelee and Baldwin[3] have pointed out that the use of talc is by no means new. They investigated its effect in a body mainly from the standpoint of white ware. Purdy[4] reported that talc was undesirable as a flux for floor tile. Howat[5] reported that the eutectic between Maine feldspar and steatite was between 17½ and 22½% of steatite, and its temperature about 1215°C. Barringer[6] reported that ground talc bonded with precipitated magnesium silicate gave a high heat resistant body. Stover[7] reported that by partially substituting talc for whiting and lowering the flint content, he was able to produce a body resistant to heat shocks.

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[1] G. L. Gilchrest and T. A. Klinefelter, *Elec. Jour.*, **15**, 77 (1918).

[2] L. E. Barringer, *Trans. Amer. Ceram. Soc.*, **6**, 86 (1904).

[3] C. W. Parmelee and G. H. Baldwin, *Ibid.*, **15**, 532 (1913).

[4] R. C. Purdy, *Ibid.*, **7**, 105 (1905).

[5] W. L. Howat, *Ibid.*, **18**, 488 (1916).

[6] L. E. Barringer, *Ibid.*, **15**, 544 (1913).

[7] E. C. Stover, *Ibid.*, **18**, 909 (1916).

These articles and discussions give relatively little information which can be applied directly to the use of talc in a vitreous electrical porcelain. It seems desirable that there be more published information in our literature in regard to this important ceramic material.

As a possible source of MgO, talc has several practical advantages over the other sources already mentioned:

1. It is plentiful, and relatively cheap. The cost of MgO from this source is much less than when brought in through magnesite or magnesia.
2. Talc is non-abrasive.
3. It has a small amount of plasticity.[1]
4. It does not give off an objectionable amount of gases in firing.
5. It contains a large percentage of SiO_2. This would tend to reduce the percentage of calcine necessary in the body.

Through taking advantage of these properties of talc, it seems possible to develop a relatively cheap high tension, insulator body, somewhat similar in final composition to the spark plug porcelains of the Bureau of Standards. In general, this was the purpose of the group of experiments described in this article. The maturing temperatures, however, of the bodies to be developed was limited to between cones 9 and 11. This required the retention of part of the feldspar to secure vitrification at this temperature. All of the feldspar was omitted in two of the bodies but this was only for theoretical reasons, not in the hope of obtaining a vitrified body.

Group I

The purpose of this group of bodies was to obtain some idea of the relative fluxing actions of K_2O introduced as feldspar and MgO introduced as talc in the empirical formula of a typical high tension insulator body. (No. 1.)

Body No.	K_2O	MgO	Al_2O_3	SiO_2
1	0.21	....	1.0	4.45
2	0.105	0.105	1.0	4.45
3	....	0.21	1.0	4.45

BATCH WEIGHTS

Body No.	Eureka feldspar	Vermont talc	Clay base	Penna. flint
1	34.0%	...	48.5%	17.5%
2	16.7	3.2%	55.5	24.6
3	....	6.5	62.4	31.3

From the results of previous analyses, the feldspar was assumed to be approximately 84% feldspar and 16% quartz.

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[1] C. W. Parmelee and G. H. Baldwin, *Trans. Amer. Ceram. Soc.*, **15**, 543 (1913); P. Rohland, *Sprechsaal*, **39**, 673–4 (1906).

Method of Making and Testing

The methods used in forming, drying, burning, and testing are similar to those previously reported and need not be repeated here.[1]

RESULTS (CONE $9^3/_4$)

Body No.	Shrinkage in per cent of wet length Drying	 Burning	 Total	Absorption in per cent of dry weight Min.	 Max.	 Aver.
1	3.6	10.2	13.8	0.07	0.11	0.09
2	3.8	11.0	14.8	0.87	3.02	2.24
3	4.6	4.8	9.4	14.86	15.70	15.17

Body No.	Dye test	Modulus of rupture, lbs. per sq. in. Min.	 Max.	 Average
1	Non-porous	6850	9200	8340
2	Very porous	5220	7000	5940
3	Very porous	3100	3700	3420

	RESISTANCE TO TEMP. CHANGES No. of heats withstood Min.	 Max.	 Aver.	IMPACT TEST No. of in. of drop Min.	 Max.	 Aver.
1	1	15	6.3	5.5	13.5	10.0
2	7	17	11.0	4.0	5.7	4.9
3	3	6	5.4	3.4	6.7	4.4

	Fracture	Color	Defects
1	Vitreous	White	....
2	Vitreous	White	Blistered—overfired
3	Rough	Very white	Underfired

Conclusions

1. K_2O has a much greater fluxing action at the temperature used than the same number of equivalents of MgO.

2. Since Body No. 2 is overfired, it is evident that the replacement of half the K_2O by MgO gives a greater fluxing action than with an equal number of equivalents of K_2O or MgO alone.

3. The introduction of MgO at the expense of K_2O increases the resistance to temperature changes within limits of composition which cannot be defined on this small amount of data.

4. The data on modulus of rupture and impact are of little value since Body No. 2 is overfired and Body No. 3 is underfired.

Group No. II

In addition to replacing feldspar by talc on a purely theoretical basis as was done in Group I, it was also thought well to replace feldspar by talc directly, pound for pound, to determine the relative effect of the two on that basis.

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[1] Robert Twells, Jr. and C. C. Lin, *Jour. Amer. Ceram. Soc.*, **4**, 195 (1921).

Body No.	Feldspar	Talc	Clay	Flint
1	34.0%	....	48.5%	17.5%
4	....	34.0%	48.5	17.5

RESULTS (CONE $9^3/_4$)

	Shrinkage in per cent of wet length			Absorption in per cent of dry weight		
Body No.	Drying	Burning	Total	Min.	Max.	Average
1	3.6	10.2	13.8	0.07	0.11	0.09
4	4.5	2.0	6.5	21.82	22.40	22.03

		Modulus of rupture, lbs. per sq. in.		
Body No.	Dye test	Min.	Max.	Aver.
1	Non-porous	6850	9200	8340
4	Very porous	1740	2350	2124

	RESISTANCE TO TEMP. CHANGES No. of heats withstood			IMPACT TEST No. of in. of drop		
	Min.	Max.	Aver.	Min.	Max.	Aver.
1	1	15	6.3	5.5	13.5	10.0
4	10	17	13.3	4.5	7.5	5.8

	Fracture	Color
1	Vitreous	White
4	Rough	White

Conclusions

The results of Group II confirm the results of Group I: that at this temperature talc alone is not nearly as powerful a flux as feldspar, and that talc under certain conditions gives a body more resistant to temperature changes.

It is interesting to note that although No. 3 contains less talc, it is nearer vitrification at this temperature than No. 4. The latter, however, is much more resistant to heat changes.

Group III

The most promising field lay between Bodies 1 and 2. Group III was designed to cover this area. It consists of 28 bodies numbered from 5 to 31. Bodies 24 and 28 were not made up. Bodies 25 to 27 and 29 to 31 were made up after the preliminary trials of the other bodies had been seen. To prevent the raw clay content from becoming excessive in the bodies containing only 0.14 and 0.16 equivalents of RO, all but 48.5% of the raw clay was introduced as calcined clay. Only the corner members were blunged up, the rest being made by blending the corner bodies. (See Fig. 1.)

BATCH WEIGHTS OF THE CORNER BODIES

Body No.	Feldspar	Talc	Calcined clay	Clay base	Flint
5	47.2%	...	...	42.6%	10.2%
8	25.8	4.2%	...	51.0	19.0
20	28.8	...	...	50.8	20.4
23	15.8	2.5	...	56.0	25.7
25	21.8	0.8	5.0%	48.5	23.9
27	16.6	2.6	15.5	48.5	16.7
29	19.4	0.6	6.2	48.5	25.2
31	12.5	2.0	8.6	48.5	28.4

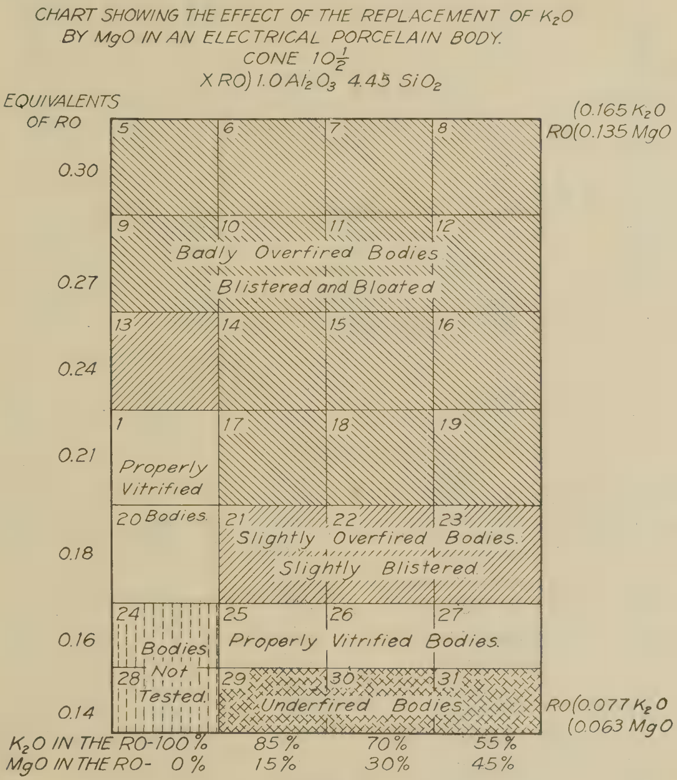
CHART SHOWING THE EFFECT OF THE REPLACEMENT OF K_2O BY MgO IN AN ELECTRICAL PORCELAIN BODY.
CONE $10\frac{1}{2}$
$X\ RO)\ 1.0\ Al_2O_3\ 4.45\ SiO_2$

FIG. 1.

RESULTS (CONE 10½)

Body No.	Shrinkage in per cent of wet length Drying	 Burning	 Total	Absorption in per cent of dry weight Average
5	4.0	8.0	12.0	0.69
6	5.5	4.5	10.0	4.85
7	4.5	6.5	11.0	4.59
8	6.0	6.0	12.0	4.85
9	4.5	8.5	13.0	2.89
10	5.0	8.0	13.0	3.55
11	4.5	7.0	11.5	4.75

TABLE (*Continued*)

Body No.	Shrinkage in per cent of wet length Drying	Burning	Total	Absorption in per cent of dry weight Average
12	5.5	7.5	13.0	4.81
13	5.0	10.5	15.5	0.15
14	4.5	7.5	12.0	2.82
15	4.5	8.5	13.0	4.67
16	5.5	8.5	14.0	3.17
1	4.0	10.0	14.0	0.15
17	5.5	9.0	14.5	1.82
18	4.5	9.5	14.0	1.30
19	4.5	9.5	14.0	1.06
20	5.0	11.0	16.0	0.14
21	5.0	10.5	15.5	0.17
22	5.5	10.0	15.5	0.29
23	5.5	10.0	15.5	0.65
25	5.0	12.0	17.0	0.09
26	5.1	10.7	15.8	0.15
27	5.5	11.9	17.4	0.08
29	3.6	10.4	14.0	0.63
30	4.9	10.1	15.0	1.33
31	5.9	9.5	15.4	2.78

	Dye test	Modulus of rupture, lbs. per sq. in. Min.	Max.	Aver.
5	Non-porous	3900	5500	4730
6	Very porous	4250	4670	4510
7	Very porous	3320	5020	4510
8	Very porous	3800	5150	4800
9	Very porous	3960	6900	5430
10	Very porous	4000	5750	4430
11	Very porous	3320	4650	3980
12	Very porous	4050	7790	5840
13	Non-porous	4440	7260	5990
14	Very porous	4410	6850	5630
15	Very porous	3580	5650	4930
16	Very porous	4360	6950	5480
1	Non-porous	7550	8900	8360
17	Very porous	4330	5880	5200
18	Very porous	5180	6400	5800
19	Very porous	5880	7740	6820
20	Non-porous	5040	7200	6125
21	Very porous	5840	11100	8550
22	Very porous	5970	8090	7000
23	Very porous	5640	8900	7040
25	Non-porous	...	...	6975
26	Non-porous	...	...	8360
27	Non-porous	...	...	9400
29	Very porous	...	...	8080
30	Very porous	...	...	7800
31	Very porous	...	...	6200

The heat resistance test was not made because the furnace normally used was needed in production. The impact test was made, but the results are omitted since they merely confirm the results of the modulus of rupture test without being as accurate.

Conclusions (Cone $10^1/_2$)

1. A very small amount of talc greatly decreases the amount of feldspar necessary for vitrification.
2. Additional amounts of talc have a much less noticeable effect than the first small addition.
3. Bodies containing talc have good strength when properly vitrified. The results of the tests on the properly vitrified bodies indicate that within limits the transverse strength tends to increase as MgO is substituted for K_2O.
4. About 0.16 equivalents of RO are needed for vitrification at this temperature when small percentages of talc are used. This corresponds to about 15% to 22.5% of feldspar depending on the amount of talc used.

The effect of the addition of talc is of course very similar to what is expected when any mineral containing alkaline earths is used. The above series, however, helps to throw some light on the best way to proportion the various body constituents.

Group IV

The next step consisted in applying the information learned towards a more practical body than any tried thus far. Group 4 was part of a

BATCH WEIGHTS

Body No.	Feldspar	Talc	Whiting	Clay base	Flint
1	34.0%	...	...	48.5%	17.5%
32	22.5	0.75%	...	48.5	28.25
33	16.9	...	3.1%	48.5	34.0

The materials are the same as those previously used.

RESULTS (CONE 9)

Body No.	Shrinkage in per cent of wet length Drying	Burning	Total	Absorption in per cent of dry weight Average
1	3.3	12.1	15.4	0.03
32	5.0	10.0	15.0	0.01
33	5.1	10.3	15.4	0.05

	Dye test	Modulus of rupture, lbs. per sq. in. Average
1	Non-porous	7700
32	Non-porous	7850
33	Non-porous	7550

series using various fluxes. For this reason but one body of this type was tried. It is similar to Body No. 25 with the calcined clay replaced by flint. For comparison the data is also given on an electrical porcelain similar in type to Body No. 27, but containing whiting for talc, and flint for calcined clay.

The appearance of all three bodies is very similar. All are straight white in color, and properly vitrified.

No very definite conclusions can be drawn from the trial of one or two bodies. The results indicate that in the development of transverse strength, the type of flux or the relative percentages of fluxes are not as important as the proper vitrification of the bodies. The chief point of interest is that in Body No. 32, 0.75% of talc has allowed the feldspar to be cut from 34% to 22.5% without decreasing the vitrification or strength.

Due to other experiments no dielectric tests were made on the latter part of these bodies. It is doubtful whether, in a body of the type of No. 32, the hot dielectric strength would be greatly increased. If this is true, the next logical step towards the development of the desired superior high tension insulator porcelain, is to try vitreous bodies, fluxed entirely or almost entirely by MgO introduced through talc. To do this it seems necessary to increase the temperature at which the body is to be fired. Higher temperatures, of course, mean added difficulty and expense, but tunnel kilns and better refractories have made these temperatures more practical commercially than they have hitherto been.

HIGHLAND PARK, MICH.

REFRACTORY CLAYS OF ILLINOIS[1]

By C. W. Parmelee[2]

ABSTRACT

A brief discussion of the geological occurrence of the fire-clay beds in Illinois and the results of testing samples which are typical of various areas.

Introduction.—An examination of the geological map of the state of Illinois will show that almost all of it is covered by a heavy mantle of glacial material. Buried under this lie the coal measures, excepting in the northernmost counties and the extreme southern tip. Along the western side of the state beginning at the extreme south and roughly paralleling the course of the Mississippi River and in the north central part of the state we find exposures of these Pennsylvanian beds which afford opportunities for mining the clays and shales which lie interbedded in these deposits. Across the southern tip of the State we find an extension of the Embayment area. In Union County which lies a little north of this tip of the Embayment area there is an isolated deposit of much importance. Besides these areas we have the occurrence of clays and shales with coal beds which are at a considerable depth and are accessible only as the coal is mined. This, in brief, is the general outline of the occurrence of the refractory clays in Illinois. Considering them more in detail we will begin with those found in the Embayment area in the extreme southern portion.

Embayment Area.—At a period subsequent to the formation of the Coal Measures, the Gulf of Mexico extended northward as a bay of comparatively narrow width considering its great length. This bay covered the western portion of Tennessee and Kentucky and the eastern part of Arkansas. The deposits of clays and sands which were laid down in that area at that time are known to belong to the Cretaceous and Tertiary age and among them we find the very important deposits of bond clays in Mississippi and Arkansas and the ball clays, etc., of Tennessee and Kentucky. The extension of this embayment area is found in the counties of Massac, Pulaski and Alexander in Illinois. Undoubtedly, it extended somewhat farther north since remnants are found as terraces and thin beds 150 feet and more above the present valley level and small outliers have been reported at a much higher elevation which may indicate a thickness of the original deposit far greater than is apparent from the portion still remaining *in situ*.

Only the uppermost or latest of the three lower embayment formations of the Cretaceous extends into Illinois. This is correlated with the Ripley formation of Tennessee and Kentucky. It occurs in the form of a curved belt varying in width from 5 to 15 miles. The deposit consists of sands varying in color: pink, light yellow and brown. The clays are a gray, or slate color and are from 3 to 15 feet thick.

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[1] The author is indebted to Mr. F. W. DeWolf, Chief of the Illinois Geological Survey for permission to publish this résumé; also acknowledgment is made of the use of geological data as interpreted by C. S. Schroyer, formerly of the Survey.

[2] Read before Refractories Division, St. Louis Meeting, Feb. 28, 1922.

Clays from this formation have been used for many years in the manufacture of stoneware. The one deposit which is being worked is rather siliceous. A sample which was obtained by boring gave the following test:

	No. 47	No. 38
Water of plasticity	25%	38.6%
Strength of clay only in terms of modulus of rupture, pounds per sq. in	365	164
Drying shrinkage	6.8%	7.8%
Burning test		
Porosity at cone 9	7.6	14.
Color	gray	cream
Shrinkage	4.4	6
Fusion test—deforms at cone	27	30

Midway Formation.—These are the oldest beds of the Tertiary age. Their exposures along the Ohio river are in the form of a high bluff extending only a short distance. These beds are of interest because of the occurrence of fuller's earth. No refractory clays are found.

Union County.—In the northwestern part of Union County there is a limited area which is of especial interest to the ceramist as well as the geologist. In a district comprising about five square miles is found a deposit of clays of unusual character. The geology of the district includes Devonian, and Mississippian formations and not far to the north are found the Pennsylvanian formations. The region is intersected by a fault which traverses the district in a northwestern-southeasterly direction. This faulting has evidently formed basins, which apparently served at one time for the accumulation of deep beds of clay. The source of these clays has not been determined satisfactorily. It has been suggested that they may have originated through the decomposition of readily soluble Mississippian limestones of the district in the same manner as the Lutesville, Mo. kaolin deposits very evidently were formed.

On the other hand, a similarity is noted in the character of these clays as compared with certain deposits to the south and east, as well as in Kentucky, as though the original deposit may have been very extensive.

There are five kinds of clay obtained in this district: a bluish white, a white, a pink, a mottled and a brownish clay.

The clay deposits seem to have been formed in the following order. First, a white sand, then a bluish white clay. Lignite is found mixed with this clay in some deposits forming a brownish clay of very good grade since the color is due solely to organic matter and is not harmful. Next in order was the deposition of the white clay which was followed by the pink and mottled clays. The mottling as seen on a freshly cut face is very brilliant in coloring and seems to be due to the leaching of iron salts from the gravel overburden. In fact one of the curious features of the whole deposit is the shell of hematite and limonite which is found in some places at the contact of the sands and gravels with the clay. Where fissures have opened in the clay beds due to movement of the strata, thick layers of hematite may be seen following the course of percolating waters. Results of test:

	No. F	No. K_3
Water of plasticity	37.4%	41.4%
Strength of clay only, modulus of rupture in pounds per sq. in.	142.5	195.6
Bonding strength	259	202
Screen test—total residues on all screens including 200 M	5.7%	...
Drying shrinkage—in terms of dry length	5.6	11
Burning tests		
Porosity at cone 9	3.2	7
Shrinkage	11.5	14
Color	gray	gray
Fusion test—deforms at cone 33 and higher		

The overburden is gravel varying in thickness from a foot or two to fifteen feet. It consists of loess and gravel. The clays vary greatly in thickness in a limited area. On one property a shaft was sunk to a depth of 93 feet in the deposit. The whole area is not continuously underlain by clay but the district is intersected by limestone ledges due to the faulting.

The clay is dug by means of open pits or by shaft and tunnels. In the former case, steam shovels are used to remove the overburden and also to dig the clay.

The type clay from this district has the following characteristics. High plasticity which is somewhat sticky. High drying shrinkage with warping tendency. Medium to low bonding strength. It burns to a white to cream color and bluestones at the higher temperatures. A minimum porosity is reached at about cone 5 and they do not overburn at cone 14. The burning shrinkage is high and the clay is intersected by an extensive series of internal cracks; also it shows a marked tendency to warp. These clays have found use for bonding in the manufacture of crucibles, abrasive wheels and miscellaneous refractories.

The third clay zone extends along the western part of the state from St. Clair County northward through Madison, Calhoun, Greene, Pike, Scott, Adams, Brown, Schuyler, McDonough, Fulton, Warren, Rock Island and Mercer Counties. An extension of this zone is found in the north central part of the state in LaSalle and Grundy Counties. Stratigraphically we find the base of the Pennsylvanian series exposed in the counties mentioned and from this geological formation we obtain our refractory clays.

The Cheltenham formation underlying St. Louis which furnishes such excellent fire clays extends into Illinois. There are some doubts as to the correlation of the clays with this horizon in the more northern counties. David White[1] expressed this opinion a few years ago, after a study of the Coal Measures, that the clays worked at Utica belong to the Cheltenham horizon.

Later Cady[2] studied the La Salle and Hennepin quadrangles and came to the conclusion that the upper clays below No. 2 coal are probably Cheltenham.

Where the Cheltenham clays have been definitely recognized in Illinois, material may be obtained by careful selection which is said to be equal to the best of the St. Louis district.

Obviously it is impossible to enter into a detailed discussion of the clays of this zone. That data will shortly appear in a bulletin of the Illinois Geological Survey. A brief summary will be given for the more important centers of production.

Greene County.—For many years clays have been dug in the vicinity of White Hall and Drake. Most of the tonnage has been used locally for stoneware. Some clay was formerly shipped. In general, the best clays have the characteristics usually associated with stoneware clays; namely, they are plastic and have a good strength, burn to a porosity of 5% or less at cone 9 or lower, and when burned have a cream color. The fusion point is variable, ordinarily is about cone 27. Results of test:

	No. 49	No. 52
Water of plasticity	24.3%	23%
Modulus of rupture—clay only, pounds per sq. inch	369	380
Modulus of rupture—bonding test	190	244
Slaking test	23 min.	10 min.
Screen residues—total incl. 200 m	3%	14%
Linear drying shrinkage—per cent dry length	5	5
Burning tests		
Porosity at cone 9	9.6	2.0
Color	cream	gray
Burning shrinkage at cone 9	5.6	6.
Overburned at cone	15.	Not overburned
Fusion test	cone 30	26

These clays are bedded. They are covered by an overburden of 10 to 30 feet of loam, gravel, and shale. Mining is done in an open pit.

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[1] *Ill. Geol. Surv. Bull.*, **14,** 294 (1909).

[2] Cady, "Hennepin and LaSalle Quadrangles," *Ill. Geol. Surv. Bull.*, **37,** 53 (1919).

Scott County.—Cheltenham clay is exposed in the bank of Mauvias Terre Creek, one-half mile west of Exeter. It tests as follows:

	No. 65
Water of plasticity	22%
Modulus of rupture—clay only, in pounds per sq. in.	240
Sieve residues on all including 200 mesh	7%
Drying shrinkage in terms of dry length	5
Burning conduct	
Porosity at cone 9	17
Shrinkage at cone 9	4
Color	light tan
Porosity at cone 15	7
Fusion test	cone 30

Fire brick have been made at Alsey from clay taken from between a 5-foot stratum of limestone and 3-foot bed of coal. Production in 1918 reached 20,000 brick a day. According to a test of the U. S. Bureau of Standards these brick had a softening point of cone $31^{1}/_{2}$.

A sample taken from the old stock pile of the plant showed the clay to have the following test:

	Samples No. 71
Water of plasticity	22%
Modulus of rupture—clay only, pounds per sq. in.	328
Linear drying shrinkage in terms of dry length	6%
Burning conduct	
Porosity at cone 9	10
Color at cone 9	Cream
Linear shrinkage	6
Fusion test	cone 28

McDonough County.—This is one of the important clay producing centers which is rivalled only by Greene County. Clay is dug extensively near Colchester and Macomb.

The following tests represent the best of the results obtained on two samples:

	Samples No. 78	No. 75
Water of plasticity	19%	21%
Modulus of rupture in lbs. per sq. in., clay only	325	295
Modulus of rupture—bonding test	209	...
Sieve residues—all including 200 mesh	4%	...
Drying shrinkage—in terms of dry length	4	4.7%
Burning conduct		
Porosity at cone 9	15	6.8
Shrinkage at cone 9	4	11.
Color at cone 9	cream	...
Porosity at cone 15	6.5	4.0
Fusion test	cone 29	above cone 30

Rock Island County.—Lines[1] reports that fire brick were made at Carbon Cliff. When visited by a representative of the Survey in 1918, the manufacture of brick had been discontinued, and the face of the old pit was badly slumped. This is regarded as of the Cheltenham horizon. Samples of clay gathered elsewhere in the county proved to be too fusible to be considered as refractory clays.

LaSalle County.—Brief mention only can be made of various producers.

Utica Fire Brick and Clay Co.—The pits are situated two miles south of Utica above the river bluffs. The clay is mined, loaded into train and hauled to a tipple where it is dumped into cars at the river level, transferred across the Illinois River by barge and hauled to the plant at Utica. Besides the production of about 20,000 fire brick per day, crude and ground fire clay are shipped..

A test of a sample from the pit gave the following results:

	Sample No. 87
Water of plasticity	25.6%
Strength of clay only—modulus of rupture per sq. in	497
Bonding test—modulus of rupture in lbs. per sq. in.	290
Screen residues—total on all, including 200 mesh	2%
Drying shrinkage—in terms of dry length	9.3
Burning test	
Porosity at cone 9	8.2
Shrinkage at cone 9	5.1
Color	Cream
Porosity at cone 14	5%
Fusion test	cone 28

Pits of M. J. Gorman and Co., about 1$^1/_2$ miles from Utica.

	Sample No. 100
Water of plasticity	24.6%
Strength of clay only—modulus of rupture per sq. in	475
Bonding strength—modulus of rupture	222
Screen residues—total on all, including 200 mesh	29.0%
Drying shrinkage—in terms of wet length	7.3
Burning test	
Porosity at cone 9	6%
Shrinkage at cone 9	5.5
Fusion test	cone 31

The Illinois Clay Products Co. at Deer Park.—A 13-foot stratum of clay lies below a 3$^1/_2$ foot seam of coal. A sample taken from this clay tested as follows:

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[1] *Ill. Geo. Survey Bull.*, **30**, 72 (1917).

Water of plasticity	25%
Strength of clay only—modulus of rupture, pounds per sq. in	504
Bonding test—modulus of rupture per sq. in	302
Drying shrinkage in terms of dry length	7.8%
Burning test	
Porosity at cone 8	2.2
Shrinkage at cone 8	5.5
Porosity at cone 15	4.6
Fusion test—deforms at cone	29

Lowell Stoneware Company at Lowell.—Fire clay is found below $3^1/_2$ feet of coal in the bluff of the Big Vermillion River. The thickness of the bed varies from 12 to 25 feet and it is said to underlie about 290 acres. A sample taken from the deposit tested as follows:

	No. 90
Water of plasticity	20.80%
Strength of clay only—modulus of rupture lbs. per sq. in	420
Bonding strength	290
Drying shrinkage in terms of dry length	6.8%
Burning test	
Porosity at cone 9	9.5
Shrinkage at cone 9	5.7
Color	dark cream
Porosity at cone 15	2.0
Fusion test	cone 30½

National Fire Proofing Co.—At Twin Bluffs, the National Fire Proofing Company is taking out clay from an open cut. A sample from there tested as follows:

	No. 94
Water of plasticity	16.9%
Strength of clay only—modulus of rupture in lbs. per sq. in	140
Drying shrinkage in terms of dry length	4%
Burning test	
Porosity at cone 9	22
Shrinkage at cone 9	2
Porosity at cone 15	11
Fusion test	cone 31

The Herrick Clay Manufacturing Company situated about a mile east of the above property is mining from the same horizon. A test of the clay shows it to have a strength expressed in modulus of rupture as 157 pounds per square inch and a fusion test of cone 27.

The Chicago Retort and Fire Brick Company.—The pits of this company are about 2 miles east of Ottawa. They are manufacturing fire brick using their own clay and also clay from Missouri.

A sample taken from a 4-to-8 foot stratum at the bottom of the pit tested as follows:

	No. 101
Water of plasticity	20%
Strength in terms of modulus of rupture, pounds per sq. in. max	532
Bonding strength—max	296
Drying shrinkage in terms of dry length	7%
Burning tests	
Porosity at cone 9	13
Shrinkage	4.4
Color	cream
Porosity at cone 15	13%
Fusion test	cone 29

One-half mile south of Dayton the Dayton Clay Works mines a fire clay which tests as follows:

	Sample No. 99
Water of plasticity	15.9%
Strength of the clay alone in terms of the modulus of rupture in lbs. per sq. in.	215
Bonding strength—modulus of rupture	107
Drying shrinkage in terms of dry length	4.9%
Burning conduct	
Porosity at cone 9	19
Fusion test	cone 30

Grundy County.—A deposit of clay of exceptional interest is found in what was formerly the bed of Goose Lake. It is a flint clay in character and the only deposit of this kind which has thus far been located in Illinois. The local geological conditions suggest that this basin was separated from the main body of the Coal Measures Sea to the south and that this deposit represents an accumulation in solution basins of the Crystalline Richmond limestone which outcrops to the north. Borings to the depth of 30 feet have been made without reaching the bottom of the clay. The flint or semi-flint clay is covered by a light overburden. A test of this clay shows the following results:

Water of plasticity	18
Drying shrinkage in terms of dry length	3.6%
Bonding test—modulus of rupture in pounds per sq. in.	59.6
Burning test	
Porosity at cone 9	17%
Shrinkage	5
Fusion test about cone	28

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THE PASSING OF KING METHANE[1]

By S. R. Scholes

Forty years ago there was always great disappointment when the hopeful driller for petroleum struck a pocket of natural gas. He might be obliged to wait for several days while the gas roared into the air, before tools could be removed, or the well probed further for oil. Sometimes a "gasser" caught fire, and the great torch, consuming millions of cubic feet of gas daily, lighted the whole countryside.

Twenty years later, natural gas had become the standard glass-house fuel, and the so-called "gas-belt," comprising parts of western Pennsylvania, West Virginia, Ohio, and Indiana, became also the glass belt, and here the most of the factories were operated.

Today the price of natural gas, except in favored localities, is almost prohibitive for the manufacturer. Moreover, for several years past, the gas has been low in supply in cold weather. This is chiefly because of the increased domestic demand, for the gas-belt household must still have its wasteful grates and sometimes heating furnaces fired with gas. And in extremely cold weather, the condensation of moisture as the warm gas issues from the wells into the cold pipes sometimes chokes off a large part of the supply at the source.

Thus, in less than four decades the most ideal of all industrial fuels has run its course from a nuisance to a luxury. Many of us can recall the words of our first text-book on organic chemistry: "Methane........is found issuing from the ground in some localities." Probably more of it has issued from the ground into the atmosphere than has ever issued from pipes since it became industrially prominent. It has not yet ceased to flow; far from it, but new gas wells are more and more speculative ventures, with production barely able to keep up with the warm weather demand.

Of all the materials stored in the bosom of Mother Earth for her human sons to find and use, none other seems so ideally adapted to the caloric needs of man as natural gas. The combustion of one cubic foot of it yields a thousand British thermal units, which is nearly double the calorific value of coal gas. It is free from sulphur. It requires some ten times its own volume of air for its combustion, and the leisurely travel of the flame through the mixture makes the flame long enough for any furnace. It is clean and dustless and almost odorless. There is scarcely a place where fuel is required where natural gas does not excel. For glass furnaces it is ideal—no other word describes it.

But all of these encomiums might almost be written in the past tense, so far as the glass manufacturer is concerned. New wells are being brought in, to be sure, but they do not take the place of old ones that are breathing their last. A year or two ago, some tremendous gas wells were brought in near McKeesport, Pa. As a result of the first strike, a fever of drilling, accompanied by a worse disease of speculation and blue-sky financing, made McKeesport a familiar name on many a beautiful stock certificate. The town was bored so full of holes that it might well have been called "Sieveport." It is all over now, and the gas obtained has cost at least $1.25 per thousand. West Virginia is still producing immense quantities, but her citizens realize the fact that the gas will soon be gone. Forgetting that the control of interstate commerce is purely a Federal function, they tried to prevent by law the piping of gas out of the State. If this had been a constitutional procedure, the glass factories of adjoining states would have been brought a little earlier face to face with the problem of finding a successor to King Methane. Oklahoma and other western states are developing gas fields, but they are too far from the centers of population to be industrially important.

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[1] Presented at the St. Louis Meeting, Feb. 28, 1922.

During the gradual shortening of the gas supply as winter followed winter, glass factories, to avoid periodical shut-downs, have been obliged to be prepared to use alternative fuels. Chief among these is producer gas, the stand-by before natural gas was known. Fortunately for industry, the inventors of gas-producers have so spent their time during the years when sooty, tarry, poisonous, evil-odored producer gas was kept from the field by its sweet-breathed cousin, that the producer to which the glass manufacturer turns today is an entirely different piece of apparatus from that of a generation ago. Mechanical poking, pressure regulation, pyrometric temperature control, and improved design and construction have made the generation of producer gas from soft coal far more of an exact process. The furnace teaser can count on gas under steady pressure, with a heat value approximating at all times 140 B.t.u. per cubic foot.

It is a difficult matter to bring up a cold furnace with this gas, but when once the regenerator checkers are heated, the maintenance of constant high temperature is only a matter of care. The one outstanding drawback is the necessity of burning out once a week the soot and tar accumulated in the mains. And apparently the soot and tar are actually desirable, to give the flame of producer gas a luminous character, so that it will radiate more heat upon the glass in tanks, or upon the pots in furnaces than would the non-luminous flame of the clean gas, whose principal fuel component is carbon monoxide.

It is within the range of possibilities that coal gas from by-product coke ovens may be made for glass furnaces. Perhaps such a development must wait until the immense tonnage of coke that would be thereby produced can find a market. Or perhaps a combination of coal- and water-gas, such as many city gas-works produce, may be made at a cost where its advantages of cleanliness and high heat value enable it to compete with that dirty but inexpensive fog, producer gas.

Fuel oil has reached an importance such that it deserves more than honorable mention as a glass-house fuel. For the benefit of those who are not acquainted with this fuel, it should be said that most fuel oils are black, heavy, and viscous. They require to be pumped warm, and are usually fed to the burners at temperatures of 120°F or higher. Several types of burners are in use, and the spraying of the oil into the furnace is accomplished in various ways. Large and small nozzle orifices, low and high pressures of oil and the air that atomizes it, are all more or less successful, and all require the same careful attention. The choice of an oil-burning system may be said to be a matter of individual preference, depending somewhat on the furnace to be heated.

The oil flame is very hot and incandescent, and therefore well adapted to glass melting. It is a trifle too short and intense, however, and local over-heating of refractories is an evil attending its use.

In the matter of cost, oil fluctuates rapidly and widely, according to the demand and supply. It also has a seasonal swing in price, being more expensive in cold weather. Therefore it requires a careful purchasing agent to keep a factory supplied with oil at an advantageous price.

Having discussed the sources of heat, let us turn for a little to the application of the dearly-bought B.t.u.'s. One ton of good bituminous coal will furnish 28,000,000 B.t.u., about 30% of which heat is lost in the conversion to producer gas, leaving 19,600,000 B.t.u. delivered to the furnace. In a good tank, where the glass need not be too clear, this coal will melt 3,000 lbs. of glass, where 1,000 lbs. is fed as cullet, 2,000 lbs. as raw material. The following figures, which are typical rather than exact, may be derived:

Heat consumed in decomposing soda		745,000 B.t.u.
Heat produced by formation of sod. sil.	352,000	
Heat produced by formation of calcium sil.	43,000	
		395,000 B.t.u.
Net heat consumed by chemical reactions		350,000 B.t.u.
3000 × .2 (sp. ht.) × 2500 =		
Heat absorbed by glass at maximum temperature		1,500,000 B.t.u.
Total heat consumed by melting glass		1,850,000 B.t.u.

$\frac{1,850,000}{19,6000,000}$ gives .094, or 9.4% efficiency.

Of the remaining heat units produced from the combustion of a ton of coal, 4,200,000, or 21.4%, go up the stack, assuming that the stack gases are at 600°F. The balance of something over 69% is lost by radiation.

While the heat balance worked out above is on the basis of coal burned, the same results are found when natural gas or oil is the fuel, since these three fuels replace one another in proportion to their calorific power.

The item of 69% lost by radiation is a conservative figure, since few tank furnaces turn out as much as 3,000 lbs. of glass per ton of coal burned. And in pot furnaces this output drops below 2,000 lbs. and is sometimes as low as 1,000 lbs. The question arises how this enormous loss may be cut down, or to put it positively, how the meager efficiency of the glass furnace can be raised. The obvious answer is, apparently, by heat insulation. The walls and crown of the furnace are nowhere more than one foot thick. Why not cover these, and also the walls of regenerator chambers and uptakes, and cut down this rapid flow of heat? The answer is that tank-blocks, crown and checker bricks, are now right at the limit of their endurance, and it seems essential to their preservation to keep them cool on the outside, and allow the heat to flow through them. Otherwise they would respectively dissolve in the glass, or spawl off in fragments or slag down, thus causing more loss than the saving of fuel could offset.

While these remarks set forth the present status of glass-house refractories, they do not mean that we are at the end of progress in this direction. The time has come when the makers of refractories must develop something that will stand up for its usual life in a glass furnace, covered with insulation. In the heyday of King Methane's reign, when natural gas sold for six cents a thousand feet (with or without a factory site thrown in) nobody minded the waste of gas. But now, with gas at forty-five cents and up, and little to be had, and coal at six dollars, and oil at whatever the traffic will bear, something real must be done to economize fuel.

Another direction in which effort might well be expended toward the saving of fuel is in the design of glass furnaces and tanks. When a civil engineer sets out to build a bridge, he has at his command accurate data on stresses, strength of materials, and the like. And, barring the occasional slipping of a decimal point, his bridge will be safe for its traffic, without waste of steel. But are there any like data for the builder of a glass tank? Does anyone really know how high the crown should be, or what is the best width of tank and length of melting end for a given tonnage, or what the shape and size of ports and checkers should be, for the most efficient operation? Apparently not, for there are a great variety of tanks, different in design according to the whims of their builders, with no demonstrated standards anywhere. This should not be so, for there are undoubtedly definite principles making for economy of fuel in glass furnaces, and it is time they were established and made known.

With true American prodigality, we have already blown into the air or burned almost all of our treasure of natural gas. And now, with true American inventiveness, we must improve furnace and refractories so as to get far better efficiencies from the burning of King Methane's successors.

Federal Glass Co.
Columbus, Ohio

Discussion

J. C. HOSTETTER:—The discussion of this paper seems to me to take in everything connected with glass melting, and while it is unfortunate that Mr. Scholes is not here to reply to your comments, I hope we may have a generous discussion of the paper among ourselves, even in his absence.

It may be of interest to you to know of the successful installation of concrete oil storage tanks at the present time. We installed one recently in Corning, with a capacity of about seventy-five thousand gallons, and it is working out successfully. It is "fool-proof," in the sense that if any leakage should take place, it is shown immediately by the water seal on the outside; that is, an indication is given immediately. The tank is divided into two compartments each equipped with sumps for collecting water and debris introduced with the oil. A steam heating arrangement maintains the oil at a constant temperature throughout the year or at least, above a certain minimum temperature, and it is working out successfully. This storage capacity cost us about $14,400 at the peak of prices including excavation, so that compared with steel tanks the cost is not excessive.

MR. H. L. DIXON:—You know, in all the years I have been engaged in the practical business of building and developing furnaces for making glass, I have grown more and more every year to realize my lack of technical education in these matters. I have grown more and more every year, as I attend meetings of this character, to appreciate the wonderful work that the technical boys are doing in the development, in the explanation, in the disclosure of all of the great forces that we have been using for years and years, in the use of fuel in the making of glass. Of course, I don't know anything about glass except in a casual way.

Now, there are one or two statements that Mr. Scholes makes that I take exception to. As a result of experiments, trials and demonstrations we have derived certain fundamental principles which we use in designing furnaces that don't exactly demonstrate properly. There are certain fundamental rules that have not been determined by any scientific method or by the schools, or any scientists, or anybody, but which have been determined absolutely by practice. The area, for instance, of a tank for melting a certain amount of glass has been absolutely determined. There is, of course, a difference of opinion, different builders and different methods; but there are very well established fundamental rules nevertheless. For instance, if a man wants to build a tank to make fifty tons of glass in twenty-four hours, there are well-fixed rules for establishing what size that tank should be.

I agree with Mr. Scholes that one of the most serious problems that furnace builders have to contend with is the matter of refractories. The materials from which the furnace must be built ought to be the subject of very intensive study of just such organizations as this. The ordinary furnace builder like myself doesn't know very much about the science of fuels and of refractories except as gained through constant use and experience. Of course, we read all these papers and try to digest them, and if we run across certain things we do not understand, we go into our libraries and dig out our text books and try to understand them, but when we get through we know very little more than when we began.

Now, the fact is this: What we can do, and what we can promise a customer, for instance, is based absolutely upon what we have experienced and gone through in our day and time. I will say frankly and I believe every man within the sound of my voice will agree with me that we learn a hundred times more through our mistakes than we do through our success. If we happen to build a furnace for somebody, and it doesn't work right we have to pay for it; and we do not forget that.

Now, is it not a reproach to those who were in the glass business during the last century that two articles they thought they had to have were by mere accident found to be unnecessary? There are a large number of men today using the main ingredients, silica, soda and lime, and a little decolorizer, and nothing else. The man that uses "dope" in his glass doesn't know the glass business. The best glass that is made today is made without "dope."

Now, I want to say, Mr. Chairman, as a man not possessing the technical knowledge that you boys do, I preach all these so much, that I can not tell you what I think of it—I cannot express my appreciation of the wonderful things that have been brought about by the study and experience of the boys that are really in the glass factories, and of what they are doing: but here is one thing I want to say. It is not a question in your study of what you can use in making glass: the intensive study you should make is as to what you can do without and abolish.

MR. A. E. WILLIAMS:—I would like to ask Dixon if he can give us the limits of insulations that can be put on the present refractories, if any can be put on at all.

MR. DIXON:—I am glad you asked that question, for we have made absolute determinations. We can insulate the parts which are subject to moderate temperatures, but when we come to the crown of the furnace—in other words, the melting chamber—if that is covered with an insulating material it only lasts a short time. It has become well known that the insulation of that part of the furnace is absolutely impossible, if you want to maintain the furnace for any length of time.

The dirt and dust and everything in a furnace accumulates on the crown, it prevents radiation causing the arch to burn through and give way in a very much shorter time than it would if it is kept perfectly clean.

MR. HESS:—The industrial application of fuel gases, I think, is rapidly assuming an entirely new aspect. It is not only a question of producing a glass or melting glass in a definite time, but the matter of the quality of the gas is a very important point to be considered, especially since we have gone into the use of automatic machinery. Undoubtedly within the next few years the development of the gas industry will be so great that in most of the gas plants, especially those located in the larger cities, it will be possible to secure a variety of gases, so we may either make our own producer gases, or we may secure gas from plants that will be located in the industrial district and which will distribute cheap fuel through high pressure lines for specific purposes. I happen to know of experiments which are now being made with blue-water gas in the melting of glass. I have tried such experiments myself, but they were in a furnace built for the ordinary producer gas and the results were not good; but, in other cases I have seen some very good results. For certain work a type of very clean gas is needed.

Some of the larger gas companies are doing a great deal of work with reference to manufacturing industrial gas locally and distributing it in the immediate vicinity to the factories. The glass factory will be able to utilize such gas for it will be available at prices which will be favorable to the specific purposes for which they are used. I think that the fuel problem should be given much attention because for certain purposes we can only use the more expensive, while for other purposes we can use a cheap fuel gas.

MR. YUNG:—It seems to me that there are a few points in the construction of tank furnaces that ought to be brought up, which have a tremendous effect upon fuel consumption. There are a good many manufacturers, who, as Mr. Dixon has said, will come to him and tell him they want a furnace of such and such a tonnage, and they want one, two or three machines to the furnace. It makes a difference whether you put one, two or three machines on a furnace in your fuel consumption per ton of glass melted. There is a point at which you will get a minimum loss through radiation per machine. If you put fifty machines around the tank, it would mean a large working diameter for your tank, and that large diameter would represent a large area of radiating surface per machine and consequently per pound of glass melted. Perhaps one machine to the tank would be going the other way. I think this is a point that the furnace builders and manufacturers should take up in the designing of furnaces—the determination of the most economical number of any particular machine to operate on a tank.

Now another subject which today is undetermined; we know that the first four or five or six inches of the tank block do not stand up very long; nevertheless, it has some value in the tank. It lasts a certain length of time; perhaps it is only two or three or four months. That being the case, just where is the balance between the cost of this extra six inches in the tank block, the pollution of the glass and the benefit derived?

Another thing that seems to me might be of help in economizing; you can lay out a tank with a radiation of fourteen to sixteen square feet to the ton. You might run the temperature of this tank up and be able to melt one and a half times as much glass. Unquestionably, the life of your tank will be shortened by increasing your temperature, but where is the balance on the cost sheet between spending that additional fuel to obtain higher temperatures, melting your flux blocks out and the increased production?

J. C. HOSTETTER:—The points brought out by Mr. Yung are very important. Going back to Mr. Dixon's reference to the technical boys Mr. Yung's statement brings in the necessary condition that if the technical man is to give us much of value, he must introduce the dollar sign into his calculations.

Referring to the thickness of tank blocks, if it is the last four or five inches of the block that counts, then put in the extra eight to make it a twelve-inch block? It is a problem, and we must get the solution to it some of these days. The life of a tank under comparable conditions is determined by the temperature of operation. I think that is unquestionably true. Therefore, to compare tank performance we should have not only the volume of glass passing through per unit time but the temperature at which it was operated, and also we should consider the area of the melting end; and perhaps the entire area of the tank. I think it is only by taking all these factors, and several others into consideration that we will be able to compare the service of different tanks and the performance of refractories.

MR. D. W. ROSS:—In some quarters the question of the thickness of the block is treated more or less as a joke. In the light of the fact that each day's extra production means a thousand or more dollars worth of ware, one manufacturer has jokingly said, that it requires only two days increase in the life of a tank to pay for the additional amount of block eaten away and also that this extra portion of block makes good glass.

MR. HOSTETTER:—There is a little bit of evidence perhaps contradicting Mr. Dixon's statement that "dope" isn't necessary in the glass.

MR. DIXON:—One thing above everything else I don't want to be misunderstood: Mr. Yung has sketched a tank for making bulbs, which all of you know is a recent development. There was a time when nobody believed that bulbs could be made from anything but lead glass. I remember that for years nobody else could make a bulb that anybody would buy unless it was made in Corning. They had a strike and the Liberty people started in competition, and that is when they first found out somebody else could make them besides the Corning Glass Works.

For years they made the bulb of lead glass from certain tanks, and they found out afterward that it was possible to make a bulb for incandescent lamps, with the proper expansion and everything of that sort, differently, and that tank he sketched out there was the result. You can easily realize it is absolutely reversed from the ordinary method of building tanks. All the methods we had had in tank building were directed to increase production. Now, all of you know we succeeded in accomplishing that. It is not a fair proposition for Mr. Yung to use his bulb tank as a general tank proposition. It is an exceptional proposition: absolutely so.

MR. WILLIAMS:—The closing paragraphs of Mr. Scholes's paper should give members of the glass division food for thought. The need of accurate data and comparative data of the fuel and furnace problems of the glass industry is becoming ever more evident as one notes the interest any article on this subject arouses.

Those who were present at the St. Louis Meeting will remember some of the interesting discussion following Mr. Scholes's paper and the many facts of interest mentioned. What a profitable meeting it would be if the great variety of opinions regarding the construction of any single type of furnace could be mentioned and compared. Could not the next Annual Meeting be made a time for special discussion of this important subject with the object of presenting comparative data on furnace construction and production.

Such a program would bring manufacturers, ceramic chemists, and engineers together with a very profitable advantage to all concerned. The Secretary of the glass division would be glad to hear from any one willing to present data or construction details at the next annual meeting such that a half day's program on this single subject might be arranged and advertised.

MR. C. D. SMITH:—In speaking of producer gas Mr. Scholes refers to the weekly burning out of the gas line as the one outstanding drawback to this type of fuel. It is true that this burning out has its disagreeable features, but with gas mains of ample capacity, properly installed dust legs with a sufficient number of openings for blowing with steam or air and a good burnout connection to stack, this work becomes a matter of routine in which most of the disagreeable features disappear.

Mr. Scholes also refers to the luminous character of the flame from raw producer gas. The application of clean non-luminous gas, a mixture of producer gas and water gas, to glass tanks is being advocated in some quarters and from a fuel standpoint is a matter on which there is a difference of opinion. To my mind a luminous flame has undoubtedly merit in tanks as now built, and when a gas having a non-luminous flame is used the B.t.u. consumption may be expected to increase 30 to 40 per cent.

DATA ON VISCOSITY OF INDIANA CLAY SLIP WITH ELECTROLYTES IN REGARD TO THE CASTING OF TERRA COTTA[1]

By H. E. Davis

ABSTRACT

A presentation of data on the use of several electrolytes with one particular clay, to wit: Indiana clay, such as is used by the terra cotta manufacturers of the Chicago district.

The various electrolytes used were sodium carbonate, sodium silicate, the two combined half and half, gallic acid, and tannic acid. Data was obtained by determining relative viscosities with the use of a flow viscosimeter, and by measuring the thickness of wall cast in a given time.

Sodium carbonate, used alone, seemed to be the most satisfactory. Tannic acid shows possibilities, but so much is required as to be commercially impractical.

Introduction

The idea of casting terra cotta has been brought up numerous times, and no doubt one may safely say that almost every ceramist in the business has experimented with it at some time or other. From the results thus far obtained by others, and those made known thus far by the Bureau, the author came to the conclusion that the idea was quite impractical because of the greatly increased plaster cost, due to the slower turn-over of the moulds. However, the hope existed that some means might be found of economically casting such work as small free-standing ornaments, balusters, etc., which are the worst pieces in the business to press, and the poorest pieces when most painstakingly made. It is no doubt problematical, but furthermore, the author is inclined to believe that the more uniform and tighter body produced in the casting process would be more resistant to the spalling troubles prevalent in work of this nature.

References

In starting this study, no attempt was made to abstract previous publications on the subject, as it was thought quite unnecessary. However, there are two papers which should be mentioned: first, one by E. G. Acheson,[2] and one by Bleininger and Hornung.[3] Acheson's paper, being the first presentation of the subject in the *Transactions*, is very interesting and instructive. Starting into the clay business as a novice, he set about to add every organic substance he could think of to certain clays, and noted the effect of water on plasticity, shrinkage, strength, etc. He even used beer and claret and obtained satisfactory results in liquefying his mixtures. The 18th amendment having ruled these out, it was considered impractical to try them in these experiments. Mr. Acheson then called upon Dr. Heinrich Ries to corroborate his results, and the most important development in the research was the marked action of tannic acid, catechu, and emulsion of oat straw in liquefying certain clays. Dr. Ries found upon microscopic examination that the effect was produced by a dispersion or deflocculation of the larger groups of particles into the minimum size of individual grain, which greatly facilitated the liquefaction.

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[1] Terra Cotta Division, St. Louis Meeting, Feb. 28, 1922.

[2] Acheson, *Trans. Amer. Ceram. Soc.*, **6,** 31 (1904).

[3] A. V. Bleininger and M. R. Hornung, *Ibid.*, **17,** 330 (1915).

The second reference, that of Bleininger and Hornung, deals with the more modern method of preparing slips for casting by the addition of small percentages of sodium carbonate, and sodium silicate. In this paper the theory of electrolysis, and the hydrolization of the salts is very fully explained, and will not be gone into here.

Scope and Methods of Investigation

From a review of these two papers, it was decided to use the following electrolytes in connection with a clay from the coal measures of Indiana such as is used entirely by the terra cotta manufacturers of the Chicago district; sodium carbonate, sodium silicate, the two combined half and half, gallic acid, and tannic acid. As relative viscosity was all that was desired, a home-made viscosimeter very similar to the one used by Bleininger, with the elimination of the Marriot tube modification, served the purpose very well. In order to eliminate as much as possible any discrepancies, due to variation in head, the tube was filled to exactly the same level for each trial. The instrument used was a brass cylinder, 8.5 inches long, 2.5 inches in diameter, with a $^7/_{64}$-inch orifice in the bottom cap. The slip made up contained 76.2 grams of dry clay per 100 cc., which weighed in the slip state 148.5 grams.

Sodium Carbonate.—In the first series run, sodium carbonate was used in the following percentages: .02, .04, .08, .12, .16, .18, .20, .24, .30, .40, added in solution with a given amount of water to 800 cc. of slip. This showed a very marked effect after addition of .04%, but no effect whatever with .02%. The greatest fluidity was obtained with .16%, and higher percentages started the curve very slowly upwards, as can be seen from the chart. Even the most liquid slip produced showed no tendency to settle out heavily. The thinnest slip in the series was cast in a small crucible mould in order to determine the thickness of wall cast in a given time, and also the total time until the piece could be removed from the mould. The average wall at the middle of the cast was $^7/_{64}$ inches and the bottom was $^1/_4$ inch thick. Two and one-half hours from the time the mould was first filled were required before the cast could be removed.

Sodium Silicate.—The second series run was with sodium silicate in the same percentages as the carbonate, added in solution with the same amount of water. The chart shows that this electrolyte was a little slower in acting than the carbonate, and required .18 per cent to produce maximum fluidity, which, however, did not reach the low point of the carbonate series. These slips were made up in the evening, and allowed to stand over night before running. By morning the bottom of each bottle of the thinner slips had about 1½ inches of clay settled so hard and gummy it was very difficult to get it into suspension again. The thinnest of this series and all others, except gallic acid, was cast in a mould the same as used for the carbonate slip for the same given time, and same results noted. In this case, the cast was removed from the mould in 1½ hours. The wall thickness was $^{10}/_{64}$ inch, and the bottom $^{17}/_{32}$ inch, which shows very clearly the rapid settling tendency. It is also noteworthy that the silicate with this particular clay allows it to free its water more readily than does the carbonate, thus producing a thicker cast in a given time.

Combined Silicate and Carbonate.—In the third series, sodium carbonate and sodium silicate were used in 50–50 proportions with quite satisfactory results. The percentages of the two combined were the same as those used for the individual components. The chart shows the combined curve to lie for the most part between the curves of the component electrolytes. As a matter of curiosity, a calculated curve was drawn up, and it is interesting to know that several of the minimum points coincide with the actual curve. Noting this, it was decided to measure the wall thickness of the casts from the three series with micrometer calipers. The results are as follows: Series No. 1 (carbonate) .116 in., Series No. 2 (silicate) .164 in., Series No. 3 (combined) .137 in. actual, .140 in. calculated.

Gallic Acid.—The fourth series was run using gallic acid solution as the electrolyte in the following percentages: .01, .02, .03, .04, .06, .08, .12, .16, .20, .24, .30, .40. Results from these trials, however, were very disappointing, and not even a curve was plotted. It was evident from the figures obtained in running the trials that the curve, had it been drawn, would not follow any definite trend, but would vary slightly from the plain slip, either up or down, with no apparent sense or reason. None of the entire series of twelve members showed any marked effect either toward thickening or liquefying the slip. Thinking that perhaps gallic acid was slow in taking effect, the slips were left until the following day, shaken well, and tried again. The figures checked very closely with those of the preceding day, so this series was given up as a failure.

Tannic Acid.—Following the results obtained by Mr. Acheson in his "Egyptianized Clay,"[1] it was decided to try tannic acid for its effect on Indiana clay. However, the range of percentage was made considerably higher than in the preceding, and the following members compose the

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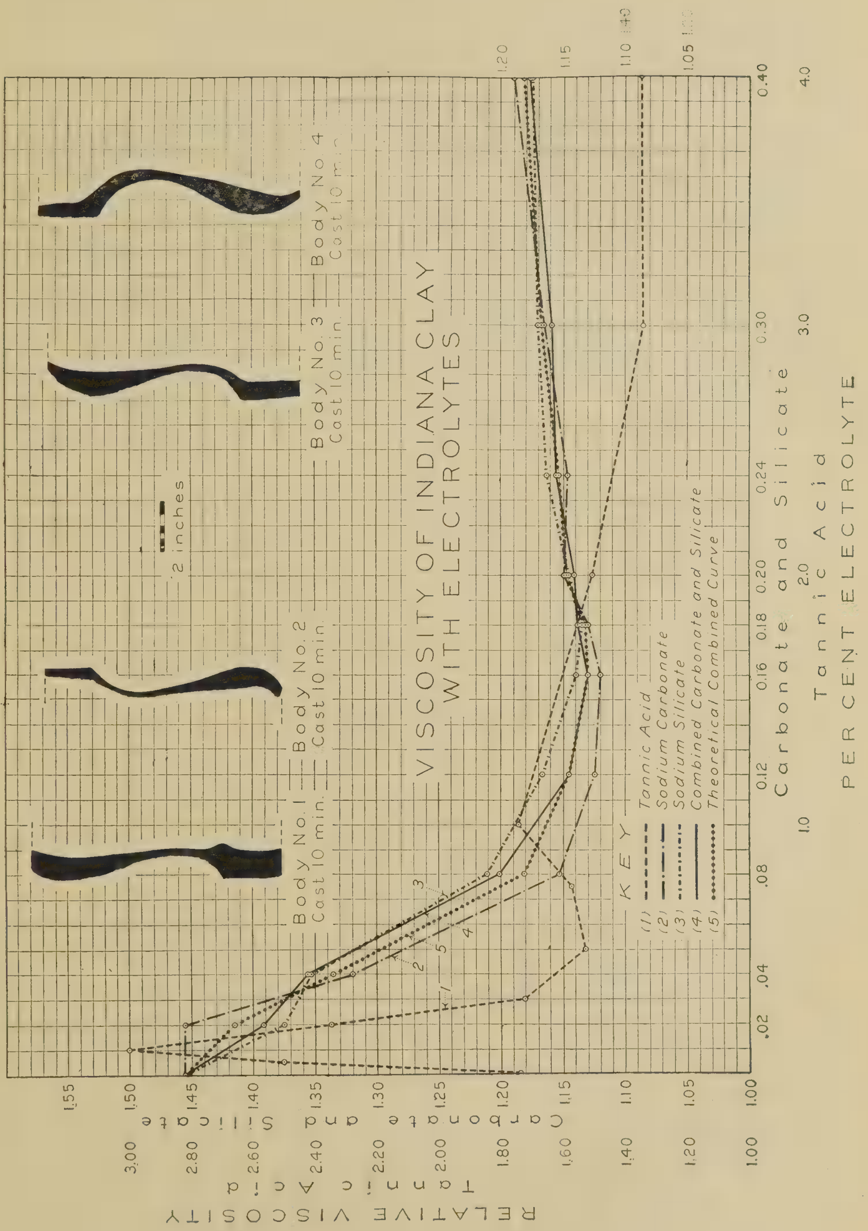
[1] *Loc. cit.*


VISCOSITY OF INDIANA CLAY
WITH ELECTROLYTES
Body No. 1
Cast 10 min.
Body No. 2
Cast 10 min.
Body No. 3
Cast 10 min.
Body No. 4
Cast 10 min.
2 inches
KEY
(1) Tannic Acid
(2) Sodium Carbonate
(3) Sodium Silicate
(4) Combined Carbonate and Silicate
(5) Theoretical Combined Curve
1
2
3
4
5
.02
.04
.08
0.12
0.16
0.18
0.20
0.24
0.30
0.40
Carbonate and Silicate
1.0
2.0
3.0
4.0
Tannic Acid
PERCENT ELECTROLYTE
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
Carbonate and Silicate
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
Tannic Acid
RELATIVE VISCOSITY
1.20
1.15
1.10
1.05

series: .05, 0.10, .20, 30, .50, .75, 1.0, 2.0, 3.0, and 4.0%, added in solution with a given amount of water. These slips were shaken thoroughly and allowed to stand 48 hours before running through the viscosimeter, as tannic acid is known to be slow acting. The results were rather startling. The first and second members increased the viscosity so that the slips were of such a muddy consistency they would scarcely run through orifice. The chart indicates very plainly this marked action and also the reverse effect of the next three members, which bring the viscosity down to the first minimum point. The following two take the curve upward, but it comes back, down to the minimum viscosity at three per cent tannic acid. Four per cent increases the viscosity slightly, so no further trials were made. It is important to note here that the thinner of these tannic acid slips were quite different in character from those of the series using other electrolytes, in that they maintained the clay in such perfect suspension and even with such a high water content showed no

TABLE I

No.	Per cent electrolyte	Rel. vis. sod. carb.	Rel. vis. sod. sil.	Rel. vis. combined
Water	. .	1.000	1.000	1.000
Plain slip	. .	1.455	1.455	1.455
1	.02	1.455	1.375	1.392
2	.04	1.320	1.353	1.356
3	.08	1.153	1.212	1.202
4	.12	1.125	1.167	1.146
5	.16	1.120	1.140	1.130
6	.18	1.130	1.135	1.138
7	.20	1.150	1.146	1.141
8	.24	1.147	1.163	1.156
9	.30	1.165	1.170	1.159
10	.40	1.190	1.175	1.177

TABLE II

No.	Per cent tannic acid	Rel. vis.
Water	. . . .	1.000
Plain slip	. . . .	1.740
1	0.05	2.508
2	.10	2.000
3	.20	2.350
4	.30	1.724
5	.50	1.530
6	.75	1.578
7	1.00	1.746
8	2.00	1.503
9	3.00	1.338
10	4.00	1.344

NOTE: A little heavier slip was used when this series was made up, which accounts for the higher viscosity figure for plain slip than in Table I.

tendency to settle over a period of several hours. This is clearly proven in the small casting made from the most liquid slip. The sodium carbonate slip cast in thirty-five minutes had a bottom more than twice as thick as the side-walls and the sodium silicate slip cast had a bottom more than three times as thick, while the three per cent tannic acid slip in the same time cast side-walls and bottom uniformly about $^7/_{32}$ inch thick, just twice as thick as the sodium carbonate slip, and was removed from the mould in one and one-half hours. A peculiar thing about this cast was the deep purple scum which appeared on the surface, due to the effect of light upon tannic acid, no doubt. This scum, however, dried to a hard casing, so hard it could *not* be scratched with the finger-nail. This shell was several thousandths of an inch thick.

Body Trials.—From the data obtained from the four successful series, four bodies were made up with grog for casting small balusters. These bodies were made as follows:

Body No. 1

Indiana clay	20 lbs.
Regular grit	10 lbs.
Sodium carbonate	14.5 gr. or .16% clay
Water	9.25 pts. (23.5%, wet basis)

Body No. 2

Indiana clay	20 lbs.
Regular grit	10 lbs.
Sodium silicate	16.25 gr. or .18% clay
Water	9.00 pts. (23.0%, wet basis)

Body No. 3

Indiana clay	20 lbs.	
Regular grit	10 lbs.	
Sodium carbonate	7.25 gr.	16% clay content
Sodium silicate	7.25 gr.	
Water	8.5 pts.	(22.1%, wet basis)

Body No. 4

Indiana clay	10 lbs.
Regular grit	15 lbs.
Tannic acid	4.75 oz. 3.00% clay
Water	4.75 pts. (24%, wet basis)

Each slip was made up with the minimum water content necessary to permit casting, and was left over night so the electrolyte could take full effect. As time was limited, no special moulds could be made, and four old baluster moulds, pretty much weather beaten, were brought in from the yard for the trials. They were put in the dry box over night, however, so they were in the best shape possible, considering all other shortcomings. Into these moulds the four bodies were poured, and allowed to stand for ten minutes only before emptying. Even with the moulds used, this was sufficient time to cast up a fair-sized wall, as is shown by the sections on the chart. Measured at the thickest part of the bowl the bodies cast as follows: Body No. 1, $1^1/_8$ in., Body No. 2, $^7/_8$ in., Body No. 3, 1 in., Body No. 4, $1^1/_8$ in. Measured at the neck, or narrowest part of the piece, the thicknesses were in order: $^3/_8$ in., $^1/_4$ in., $^5/_{16}$ in., and $^5/_8$ in. Body No. 2 was released from the mould in two hours and No. 4 was but little slower. Bodies 1 and 3, however, had to be left in the mould for a couple of hours longer, and even then were rather weak. This, I believe, is attributable partly to the position of the mould when casting. The sections on the chart show that Nos. 2 and 4 were cast with the large square base up, which left a large opening to facilitate in drying out the inside. The other two were cast with the bowl up, having only two very small holes, which I believe retarded the setting up considerably. However, the advantage of the open end with the particular mould used was at the same time a disadvantage in that the square base cast very thin on the flat side, and very thick in the corners. This, no doubt, could be overcome by proper design of the moulds for casting purposes.

Summary and Conclusions

From a study of the casts made from the plain slips, and from these same slips made up into grog bodies, certain things are evident, but too definite conclusions should not be drawn from the results of the work thus far. However, from the curve established and the cross-sections, we can safely make the following statements:

1. For casting bodies made up with typical Indiana clay, such as used by the Chicago terra cotta manufacturers, the best electrolyte, aside from tannic acid, is straight sodium carbonate, because,

(1) It produces maximum fluidity in the slip.

(2) It does *not* produce a slip which settles out heavily.

(3) When made up into a body, it casts a uniformly thicker wall than does the sodium silicate body, or one using a combination of the two.

(4) Although it was slower in drying out and releasing from the mould, this, I believe, was largely due to the shape of the mould, and can be overcome, or at least greatly improved.

2. Sodium silicate, when used as the sole electrolyte with Indiana clay, presents the following disadvantages:

(1) It does *not* hold the clay in suspension, but rather settles it out in a very hard, gummy mass in a short time.

(2) Made up in a body, even with a slightly less percentage of water than the carbonate, the wall of the baluster cast in a given time was thinner than with the latter.

(3) If allowed to remain in the mould longer in order to get a thicker wall, past experiments, not mentioned heretofore in this paper, have shown that a silicate slip will seal both next to the plaster, and on the inside, making a rather stiff shell with a soft center, which takes an incredibly long time to dry out.

3. Nothing further need be said about the use of half and half carbonate and silicate than that it produces a body, the properties of which are just about an average of those produced by the components.

4. The best results in many respects were obtained with tannic acid, and it has several things to recommend it.

(1) It makes a slip of excellent working qualities, holding a perfect suspension.

(2) Although the minimum viscosity attained was not nearly so low as with the others, it seemed to lose its water *much* more readily, as is evidenced by the large cross-section of the cast.

(3) The body when dried is very appreciably harder than any of the others. In fact it is so hard it cannot be scratched with the fingernail.

However, 3.00 per cent tannic acid is out of the question commercially as it would be entirely too expensive. Unfortunately no body was made up using 0.50 per cent of the acid, but the plan at the start was to select from each series one of the lowest viscosity, and no time was left for additional work, though it is quite evident that much more can be done in following up the leads so far uncovered. This work will include the proper designing of casting moulds, experiments with plaster to determine the maximum absorption, and possibly some further search for electrolytes among the organic acids, and it is hoped that much of this can be completed in the near future.

A study of the properties of various plaster mixes with varying water contents, and the introduction of adulterants of various types is now under way, and will be the substance of a future article by the author in which he hopes to correlate the information to be obtained to the data herein presented.

THE NORTHWESTERN TERRA COTTA CO.
CHICAGO, ILL.

Discussion

MR. W. D. GATES:—Probably I am the only one here who was present when Mr. Acheson[1] brought this question up. That was the first time that we had a paper sent out for reading before being read at the Convention. It was quite an innovation, and I remember distinctly the impression it made on me. I said to myself: "Here is a man who uses clay only incidentally as a binder in grinding wheels and yet he has made this great discovery. We have been asleep at the switch."

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[1] *Trans. Amer. Ceram. Soc.*, **6**, 31 (1904).

With a great deal of difficulty I got some of the material from some remote clime. I found that the least I could get was a bale. I got a bale. It was very interesting. It was done up in a mattress, one on top of the other, and it was much more than I wanted to buy.

I tried a few minor experiments with it, and it caught my attention because it rendered the molded clay unusually hard when dried. It occurred to me that the use of tannic acid would greatly reduce the breakage and chipping in the handling prior to burning if nothing more.

We were experimenting with some large sized bath tubs at the time, which gave an excellent chance to try it. We opened this bale and made a mixture and pressed a bath tub. Just then I started for the Convention full of enthusiasm regarding this new discovery.

When I returned home I found that the bath tub had formed a hard shell on the outside of the pressed parts, apparently sealing up the surface, and the ware was all torn with cracks and was ripped in every direction.

The proposition was very interesting in many respects, but I think that bale from India is somewhere about the factory now. The idea I had was to harden the raw clay so as to lessen breakage in handling, but the surface swelled and hardened, thus effectually so sealing up the pores that it was impossible to dry the piece. We did not go further with it.

I have never had good results with it, although I understand that it is used.

MR. DAVIS:—I understand, Mr. Gates, that you used catechu rather than tannic acid?

MR. GATES:—Yes.

MR. DAVIS:—We use tannic acid. Of course, we do not cast a very thick wall, but still there is an inch and an eighth, and there is no tendency to seal and to leave a soft center. Tannic acid does not do that. It forms a very hard shell, but it does not seal the surface.

MR. GATES:—It was catechu that I had. I could not remember the name. It is a gummy substance. We had a different condition from those described in Mr. Davis' matter. Catechu probably sealed the surface whereas tannic acid does not.

MR. THURLIMANN:—Catechu is used in medicine as an astringent, the same as tannic acid. Probably other organic astringents would have the same effect as tannic acid.

MR. GATES:—I might have better taken it as a medicine, probably.

MR. C. W. HILL:—It would seem that the casting of terra cotta on a production basis would be a valuable development, especially in the case of pieces like balusters which are difficult to press properly.

In experiments of this nature one wishes there were an easier and quicker way of finding the best electrolyte than by actual casting trials. Possibly one could get a line on the nature of the electrolyte desired by determining whether the colloidal matter in the clay under investigation is positively or negatively charged. It would be of assistance if one could classify the electrolytes on some basis which would enable the investigator to concentrate his tests on those of one class. As an illustration it might be possible to classify them as to degree of acidity or basicity or hydrogen ion concentration.

If some systematic scheme could be worked out it would assist others who wish to do the same thing with clays of a different nature, whereas by the method of trial of a wide variety of electrolytes the results which Mr. Davis would get, while satisfactory for his clay, would not be of value to others unless they had the same kind of clay. However on account of the special properties of each colloid such as the specific absorption of certain ions it is not certain that even if classification were possible in one case the same classification would hold for another.

MR. ORTMAN:—In the case of tannic acid, it is not just like adding glue to the clay, which we know will make it very much stronger and which will hold it in suspension and act in some degree as will sodium bicarbonate and sodium silicate? We experimented with different electrolytes, catechu and tannic acid, and found that the strength of the dry pieces was increased four or five times. When we burned and tested the pieces they showed no evidence of the effect of the electrolytes.

MR. THURLIMANN:—The ionization factor of tannic acid is not very great. If it is hydrogen ion concentration that is wanted why not use hydrochloric acid which shows the greatest ionization?

MR. C. W. HILL:—My mention of hydrogen ion concentration was merely as an example of a classification and not as an explanation of any of Mr. Davis' results. The best electrolyte for any clay would depend upon its colloidal nature and possibly the presence of salts in the clay.

MR. DAVIS:—A strong acid as a general thing will increase the viscosity materially. The effect of increasing concentration of tannic acid is first to raise the viscosity to the maximum and then decrease it, there being two minimum viscosity points in the curve. You could not account for that by hydrolysis of the electrolyte.

MR. C. W. HILL:—It is quite common in colloidal chemistry to find the same electrolyte producing different effects at different concentrations. I would not know how to account for the change in this case.

MR. DAVIS:—Do I understand, Mr. Hill, that in your opinion tannic acid is not an electrolyte?

MR. C. W. HILL:—It is an electrolyte. My point is that if tannic acid shows promising results you might find other compounds belonging to the same class which would be better.

Mr. C. W. Hill (Communicated):—Although the classification of electrolytes seems in this application to be desired but difficult to obtain, one can not help but wish there were a quicker way of testing the electrolytes. This is especially true if it is not possible to work by classification, since one would have to test a large number of electrolytes. Possibly a study of the effect on rate of settling would be a short cut.

On the general proposition of casting I should like to inquire whether the composition of the mould enters into the problem. It occurs to me that with plaster of Paris moulds the calcium sulphate which is somewhat soluble might have an effect which would not be found with some other porous material.

AN OIL-FIRED FURNACE FOR THE PLANT LABORATORY

By D. A. Moulton

ABSTRACT

Description of Furnace.—This is an iron-encased furnace with 1½-inch asbestos insulation. The chamber is 21 inches square by 20 inches high and will hold 14 bricks on end.

Operation of Furnace.—This requires from 16 to 20 gallons of fuel oil per heat of high temperature for a period of five hours. Pre-heated air is supplied by a No. 4 Blower running 3000 R.P.M. delivered through a 3-inch pipe.

In the *Transactions* and *Journal of the American Ceramic Society* several fusion furnaces have been described which have been quite small and require that the sample of clay or brick be tested in the form of a cone. There has always been a question as to the effect of reducing the brick to a powder because of the destruction of the texture of the brick. Often small portions of brick or cones cut from brick have been used for fusion tests, to observe the temperature at which trial pieces begin to fuse.

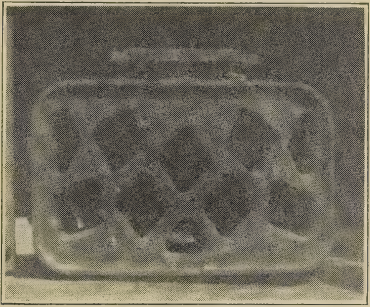


Fig. 2.

Fig. 1.

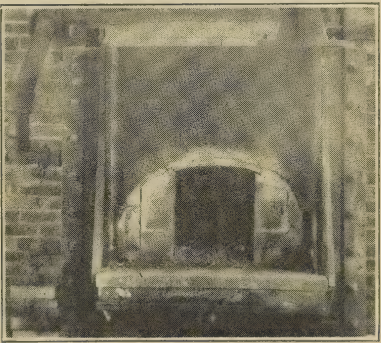
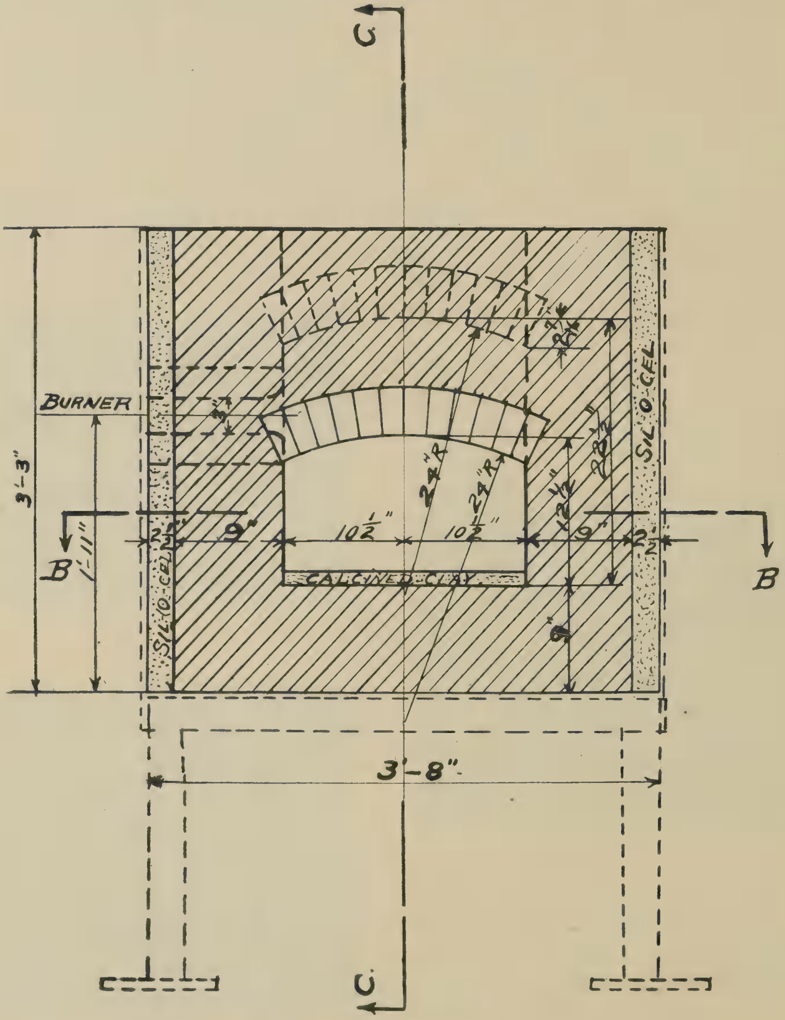


Fig. 3.

The furnace here described permits a test of the whole brick. It is large enough to hold fourteen bricks placed on end, and one cone pat. The chamber is twenty-one inches square by twenty inches high. It is oil-fired, the oil being fed to it by gravity under a head of eight to ten feet through a half-inch pipe. Two valves are used on the line, one a needle valve for accurate control.

The air is supplied by a Number Four Positive Blower, 3000 R. P. M., discharging to the furnace through a three-inch pipe. Nearly the full capacity of this blower is required to obtain a temperature of cone 34, or 3164 degrees F, as indicated by an optical pyrometer. Cone 34 can be obtained in five hours. It is believed that this furnace could obtain still higher temperatures, especially with a larger capacity blower.



FRONT ELEVATION JACKET REMOVED

FIG. 4.

The burner seen in the sketch reduces the size of the pipe from three to two inches. The two-inch pipe comes within four and one-half inches of the inside lining through a fire-clay nozzle block which flares flush with the lining. A peep-hole through the burner enables one to observe whether the pipe is clear or melted. If the pipe should collapse by softening, shutting off the oil for a moment will let the air blow it open again.

The oil is fed to this burner through the bottom into a ring which leads it to the top where it drops through a hole twelve hundredths of an inch in diameter. This small hole admits plenty of oil but owing to the small bore it is desirable to screen the oil. It requires from sixteen to twenty gallons of fuel oil for each high temperature heating of five hours duration.

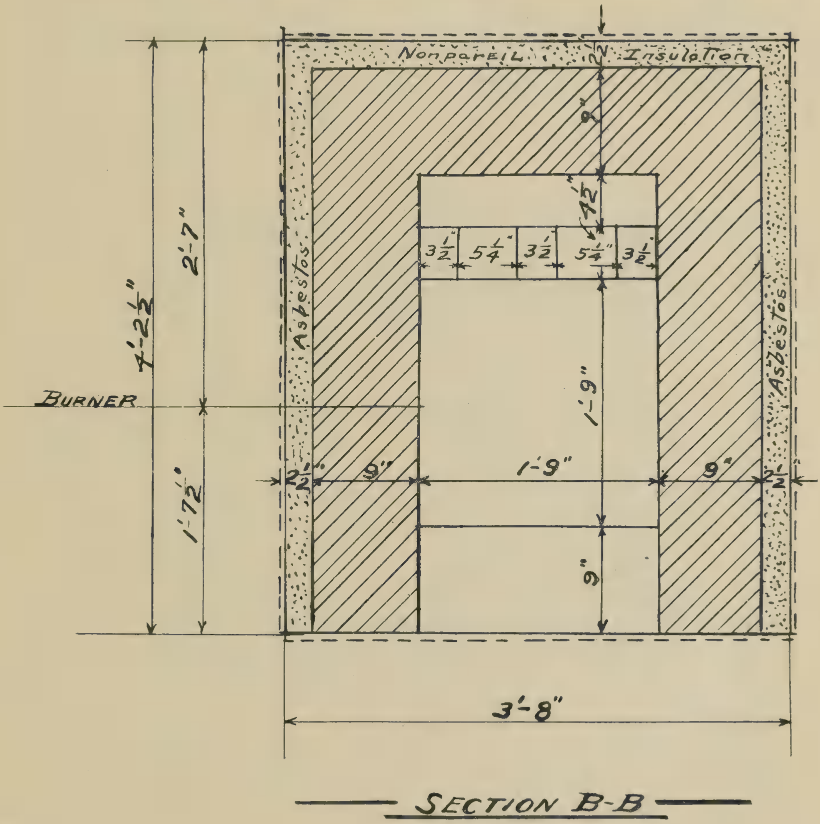


FIG. 5.

The air is pre-heated in two hollow castings placed over the outgoing flue or chimney. The two castings are alike but are placed end for end, thus staggering the openings. The air pipe just above the burner is so hot that a spray of water on it will sizzle.

The three flues to the chimney are five inches above the floor of the furnace and measure three and a half by two and a half inches.

The door of the furnace is built of fire-brick shapes. An opening in the door five inches square is closed by sliding a brick in front of it.

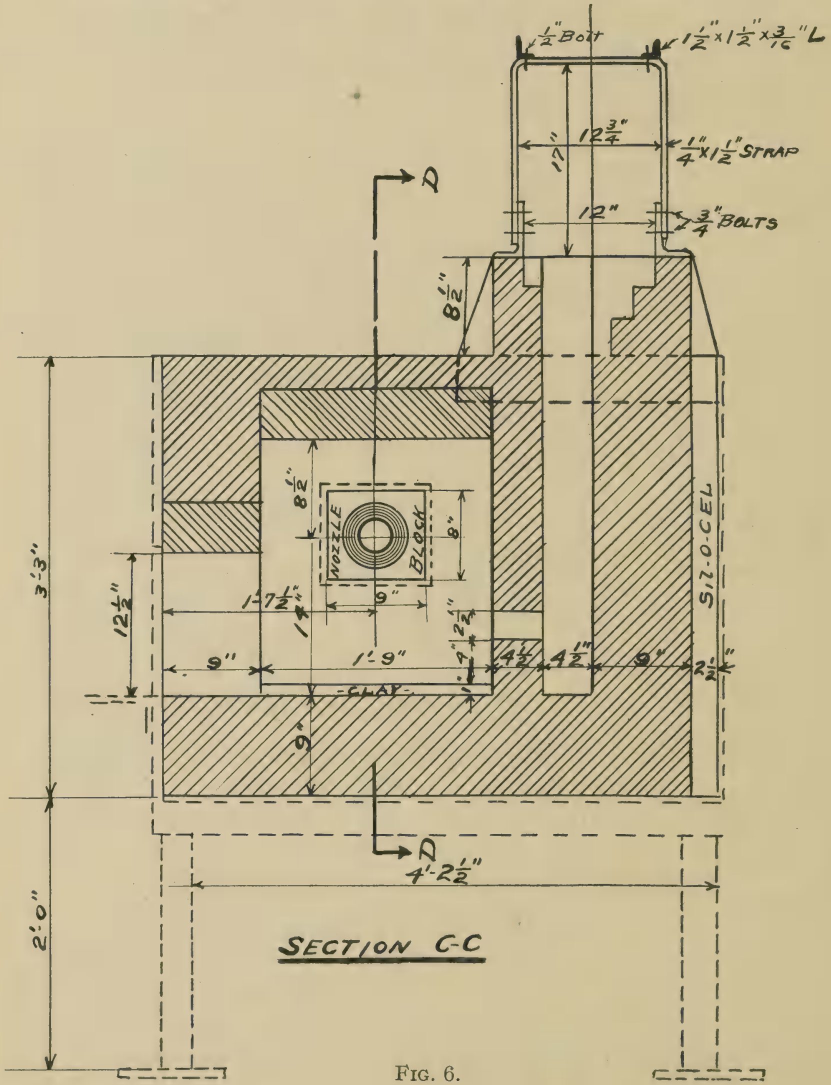
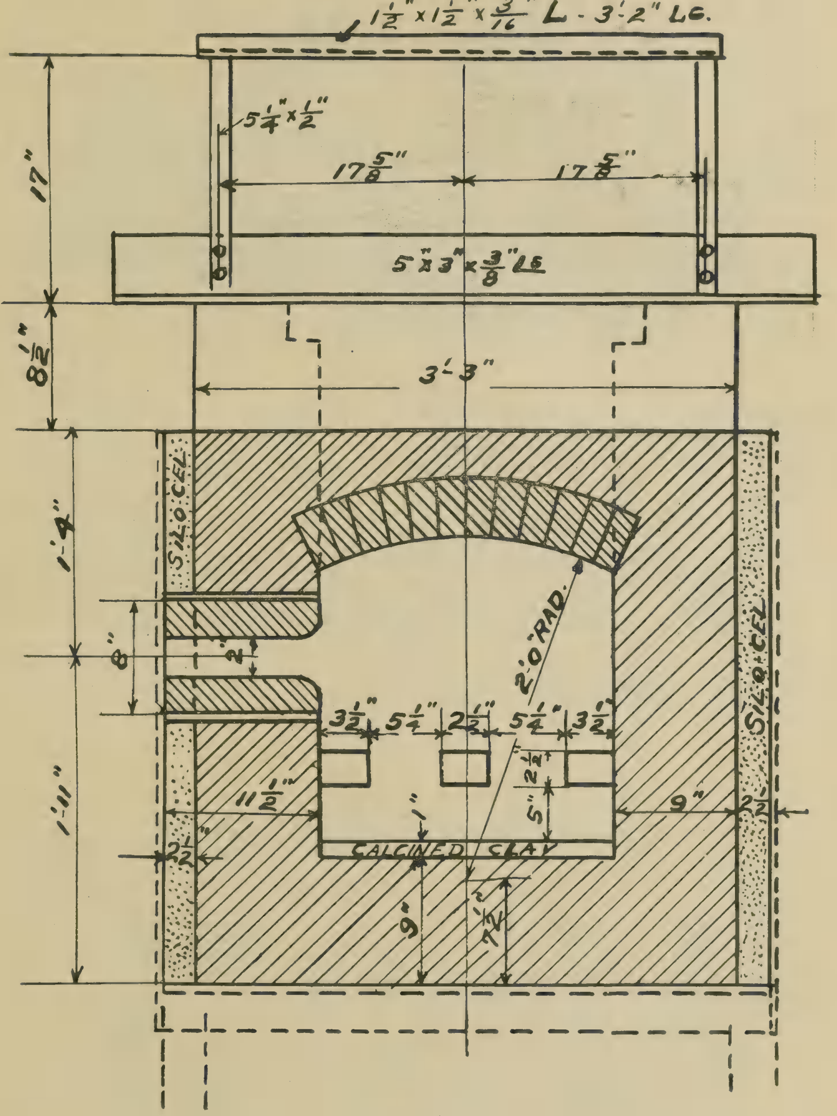


Fig. 6.

A time temperature curve of a test run in this furnace is shown in Fig. 9.

Results obtained in this furnace: Fig. 10 shows two bricks heated to 3125 degrees F, cone 32 down, and cone 33 starting. Both bricks are



SECTION D-D-

FIG. 7.

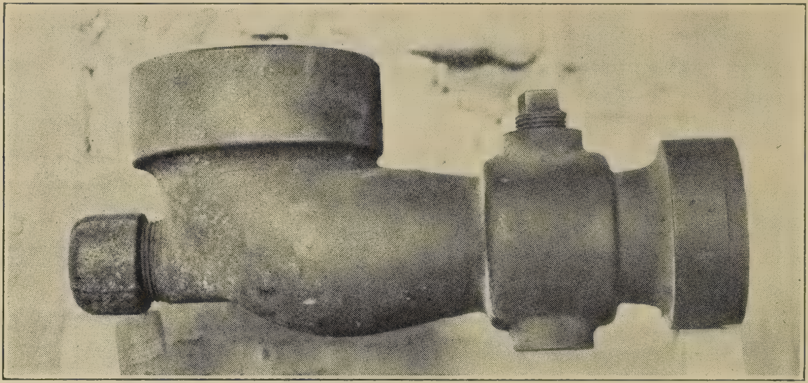


FIG. 8.

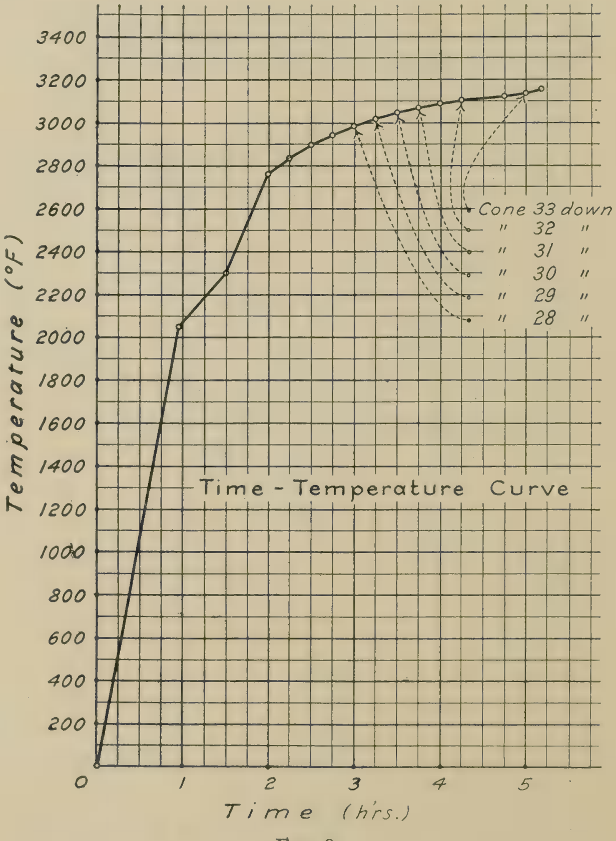

Temperature (°F)
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
2
3
4
5
Time (hrs.)
Time - Temperature Curve
Cone 33 down
" 32 "
" 31 "
" 30 "
" 29 "
" 28 "

FIG. 9.

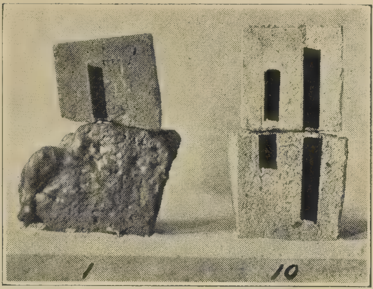


FIG. 10.

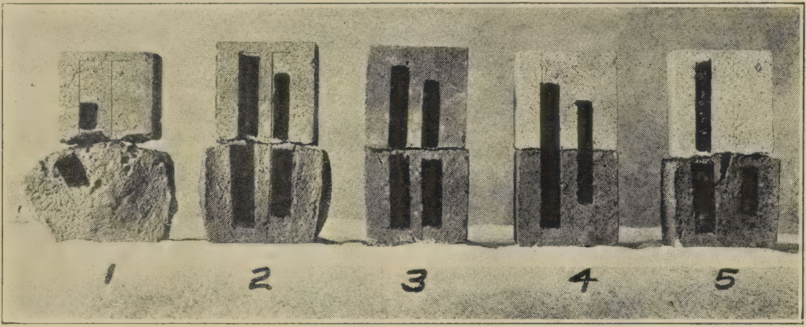


FIG. 11.

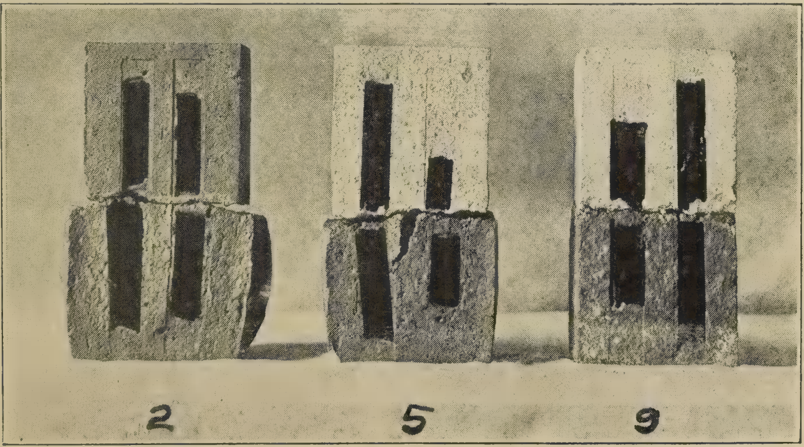


FIG. 12.

made by the stiff-mud process but at different factories The black streaks on the brick are simply obliterated trade marks.

Figure 11 is a good illustration of the effect of the process of manufacture from the same clay. No. 1 brick in this picture is, however, a lower grade of clay. No. 2 is made of the same grade of clay as No. 3. The only difference is in the process of manufacture, No. 2 being made by the stiff-mud and No. 3 by the dry-press process. The same is true of No. 4 and No. 5, both being made of the same clay which is a better quality than that used in making bricks No. 2 and No. 3. Brick No. 4 is made by the dry-press and brick No. 5 by the stiff-mud process.

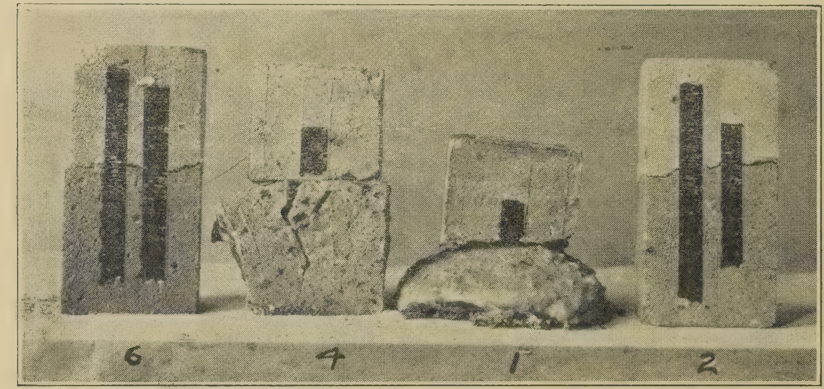


Fig. 13.

Figure 12 illustrates three brands of brick made by one firm, showing gradations according to refractoriness as graded on the market. The temperature of this test expressed in cones was cone 30 down and cone 32 starting.

Figure 13 shows two brick which were supposed to be made of southern bauxite but which melted to the above condition at 3115 degrees F, cone 32 down. Many lower grade fire brick and a few higher grade brick containing lime melt down into a puddle similar to this No. 3 brick.

This furnace may be used for running expansion tests, spalling tests, slag tests, and could be arranged for load tests.

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WATER SMOKING WITH INDUCED DRAFT[1]

By W. W. Ittner

ABSTRACT

Recitation of experience with induced draft shortening the periods of water smoking, burning of dry pressed brick and economizing on fuel.

Introduction

An article, "The Water Smoking of Clay," by R. F. Geller, appearing in the *Journal* for May, 1921, covered in a more scientific and thorough way work done along the same lines by the writer as far back as 1893.

In a cruder way, and without the aid of instruments, approximately the same ground was covered, except that in my case the work related to a particular product with the conditions of manufacture and the clay being worked, as a fixed quantity. Naturally the conclusions derived by the writer were not and can not even now be placed and presented in any such explicit and succinct manner. It does seem strange though, that a period of some 28 years should have elapsed between the time when the writer fought through his own little difficulty and the appearance of an experiment sufficiently related to attract attention.

Most clay workers have difficulty in differentiating between drying and water smoking due in greater part to a carelessness in the use of term rather than to any misconception of the subject.

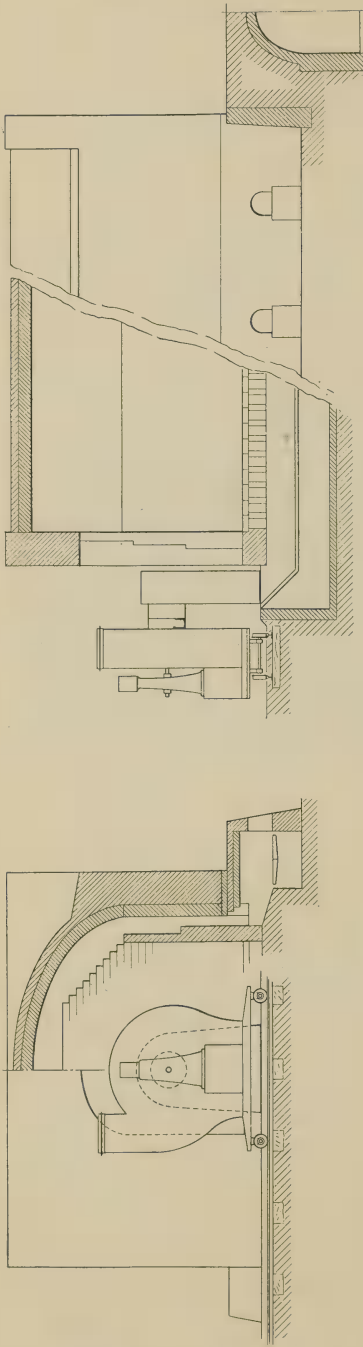
Water smoking, *per se*, is a distinct stage in the kiln process with but a "twilight zone" shading off from drying on the first hand and dehydration on the next. Confusion is brought about by a lack of distinct line between them.

The drying, if carried on in a separate dryer, and before the ware is set in the kiln, is easily distinguished from the water-smoking period. When both processes are accomplished in the kiln itself, there is no ending of the one and the beginning of the other, for both drying and water smoking are the evaporating off of mechanical water. The line between the two periods, in a given clay and under certain conditions, can be arrived at only when treating a single unit, as in Geller's experiment, rather than with an entire kiln of ware.

From a practical point of view, it is a fact that none of the separate stages into which we have divided the kiln operation occur separately and distinctly in a given kiln burn but proceed progressively as the temperature rises.

Geller's conclusions are, in my opinion, correct and of great practical value. He does not cover the practical application of his experiments, leaving this matter to the individual to apply to his own particular conditions.

[1] Rec'd March 27, 1922.



Movable Exhauster connected to Kilns by Sheet Metal Breeching to aid Drying and Watersmoking

We would have preferred more description of the success of each run as indicated by the physical condition of the clay cubes after treatment, than to have had the determining factor of success or failure hinge entirely on the thermal lag, both in regard to the penetration of the heat into the cube itself and the cube temperatures in reference to furnace temperature. The danger zone or period of greatest thermal lag is shown as lying between 100° and 250°C. However, the most severe treatment, shown by the first run in his Table I[1] in which the temperature was raised to 300°C in three hours, might, from a practical point of view, be perfectly all right, if no bad effects on the ware resulted and if it was desirable to water smoke the ware in so short a time.

It is with that portion of his conclusions referring to the use of induced draft that we expect to deal since it was through the use of this expedient that the drying and water-smoking periods were greatly reduced by the writer in length of time and at a great saving in cost.

What I have to say relates to dry press ware which is the more difficult to water smoke in a kiln as the bricks are set direct from the press into the kiln.

Description of the Case

At the time the writer took charge, it was taking some eight days for the drying and an additional eight days for the water smoking and burning. The kilns were of the rectangular down-draft type with the tunnel and stack arrangements, as shown.

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[1] Geller, *Jour. Amer. Cream. Soc.*, **4,** 377 (1921).

The drying was accomplished by the aid of an exhauster attached to the end of the kiln opposite the stack and was moved along on a track so as to serve any one of the battery of eight kilns standing in line. The exhauster was connected to the kiln tunnels by a sheet iron breeching, substantially as shown in the sketches.

TABLE I

SEVEN-DAY DRYING SCHEDULE

Hrs.	Period	RPM	Fires	Fuel	Rem.
6 12 18 24	24	100	Low as possible. End of sticks burning only in ash pits	Cord Wood	12 Cords of wood Apportioned
30 36 42 48	24	150	One stick all the way in. One-half way in	Cord Wood	
54 60 66 72	24	200	2 Sticks	Cord Wood	
78 84 90 96	24	250	3 Sticks	Cord Wood	
102 108 114 120	24	Full speed 300	One stick wood. Grates $^1/_3$ covered	Wood and coal	Coal screenings used. Fires on grates
126 132 138 144	24	300	Grates $^2/_3$ covered	Coal	
150 156 162 168	24	300	Grates covered	Coal	

The kilns had a capacity of 185,000 bricks, building size, and were set thirty-four high. Some sixteen to twenty cords of wood were being used in drying, besides an undetermined quantity of coal, after the wood was consumed. The brick were manufactured by the dry press process and of the usual red-burning surface clay.

The Experiment

It was apparent that too long a time and an excessive amount of fuel were being used in the drying and burning, hence, experiments were started immediately to reduce the drying and burning cost. The matter was gone about in a very cautious way, since up to that time the writer's very limited experience had been with the old style up-draft kiln.

TABLE II

ORIGINAL EIGHT-DAY BURNING SCHEDULE

Hrs.	Period	Fires	Fur. doors	Settle
6 12 18 24	24	Light and clear. 3 shovels	Open	
30 36 42 48	24	Light and clear. 3 shovels	Half open	
54 60 66 72	24	4 shovels	4″ open	
78 84 90 96	24	4 shovels	2″ open	
102 108 104 120	24	4 shovels	Closed	
126 132	72 hrs.	According to settle	Worked according to settle	Settle starts
138 144				1″
150 156				2″
162 168				2″
174 180				2″
186 192				2″

Without instruments of any sort to act as a guide, a schedule of drying and burning was laid out in such a manner as seemed to assure the most uniformity in the temperature increase and so as to save one day in both operations. This schedule was laid out in the form of a chart as shown in Table I. Progress of temperature increase during the drying was regulated by the number of sticks of wood that were placed in the furnaces at a time and was varied only when the feel of the air from the exhauster indicated that things were moving either too fast or too slow. The drying operation was taken to be finished when no moisture appeared on a cold iron rod thrust into the lower peep-hole and when the exhaust air left the hand perfectly dry and hot.

The burning schedule, mapped out in the same manner as the drying schedule, was then entered upon (see Table II) and its progress regulated by the number of shovels of coal at each firing and later by the appearance of the heat after the kiln had gained sufficient temperature to admit of observation through top and bottom peep-holes.

The transition from the drying to the burning operation was made as evenly and regularly as possible by the gradual slowing down of the exhauster and at the same time drawing the stack damper until, in the course of six or eight hours, the exhauster was finally stopped and removed. By this time the stack was able to pick the kiln up and go right along with very little, if any, interruption.

After the kiln became red, so that the action of the fire could be observed, the schedule was varied according to circumstances. Sometimes the fire worked through to the bottom faster than at others and the settle started more promptly or more evenly in one burn than in another. These conditions were all met in the usual manner with increased or reduced charges of coal or by the arrangement of stack dampers.

The quality of brick that were being made was of the best of this grade and while it was absolutely essential to reduce the cost of manufacture it was also essential that the quality of the ware be not impaired. To this end each shortened schedule in the drying and burning processes was watched very closely and carefully so that any defect in the quality of the ware would be noticed as soon as possible until it would be evident that the danger point had been reached and further shortening of the drying and burning time impossible.

Shortening of Drying Time.—As an aid to the writer in shortening the drying time and to ascertain what the lower limits of time might be, a great many single bricks were dried and the time of drying noted by the simple means of placing the brick in the engine room over the cylinder of the engine and bringing them closer and closer to the cylinder in gradually decreasing periods of time. Contrary to the writer's expectation, single bricks could be dried in a very short space of time without damage to the ware, this period being as low as one or one and one-half hours.

We understood, of course, that an entire kiln of brick could not be handled with the same expedition and safety as a single brick; however, the experiments went a long way in giving assurance that the essential qualities for rapid drying were present in the clay and that a shorter time in the kilns could be obtained if the proper methods of setting and drying were learned and adhered to. Accordingly the schedule for the drying in particular was gradually reduced to six, five and then to four days (see Table III) and the amount of wood, which was the more expensive fuel, reduced to three cords, when it was concluded that the end had about been reached.

The four-day schedule, which was half the original time of drying, was adhered to for quite a while until further demands on capacity (with a consequent indifference to quality) called for further reduction of time. The drying operation was carried on for several years in succession on a three-day schedule, and in several particular instances, where all conditions were undoubtedly favorable, kilns were dried in two and a half days with no material damage to any excepting to tight courses. The brick from the tight courses were weak and without the metallic ring, although they left the plant as salable ware at the time.

TABLE III
FOUR-DAY DRYING SCHEDULE

Hrs.	Period	RPM	Fires	Fuel	Rem.
6 12 18	18	150	One stick all the way in. One, half in	Cord Cord Wood	3 cords of wood Apportioned Apportioned
24 30 36	18	200	2 sticks	Cord Wood	Fires in ash pits
42 48 54 60	24	Full speed 300	Grates $^1/_2$ covered	Coal	Coal screenings Fires on grates
66 72 78 84 90 96	36	300	Grates covered	Coal	

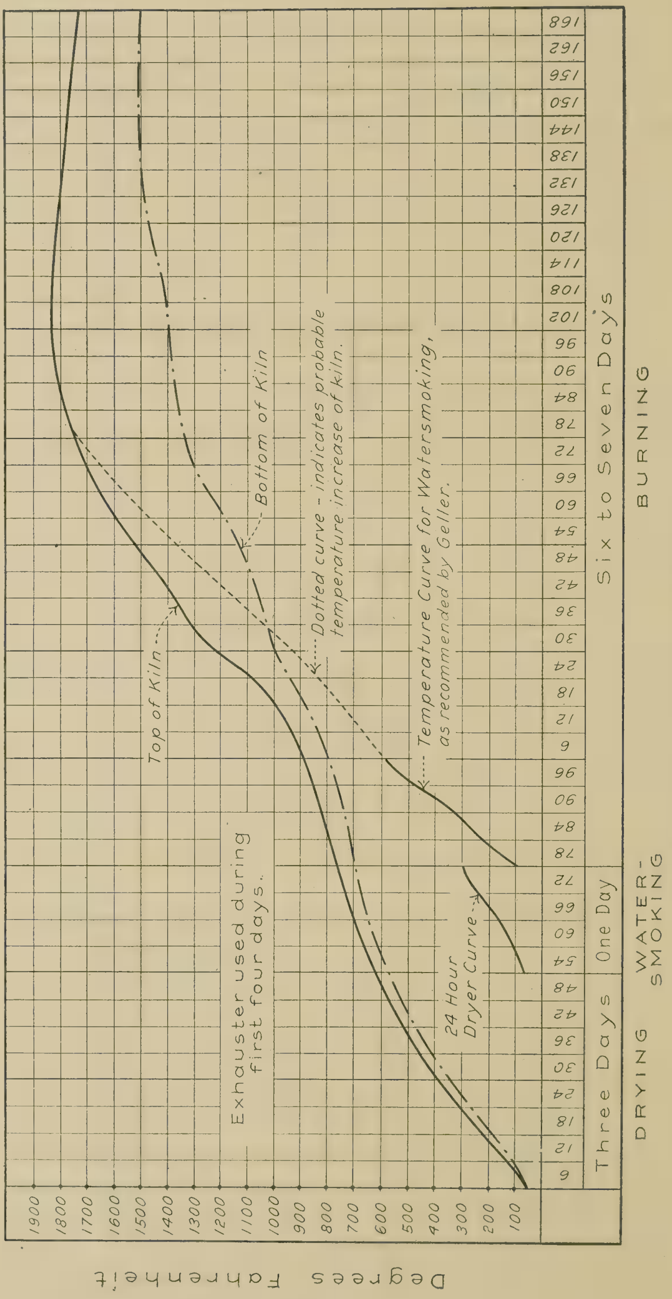
Shortening of Burning Time.—While the drying point was shortened as described, our success in shortening the burning time was not attended with any such gratifying results, since seven days was about the least time in which the kilns could be burned and proper results obtained.

The most critical time was between the conclusion of drying (when the exhauster was removed) and the time the kiln became red. We discovered that too rapid a rate of raising the temperature during this period caused the brick to lose the metallic ring and were damaged by quashing, showing false settle; and by the kiln settling unevenly. This period of burning was changed to give a slower advance with the stack draft immediately after the exhauster was removed, for perhaps 24 to 36 hours. The forced firing was then resumed until the kiln was "sweated" or evened up in temperature preparatory to starting the settle. Naturally after the settle was started the fires were worked and the kiln governed entirely by the rate of settle.

In shortening the time of burning after the kiln was dry, our sole aim at the time was to effect as rapid an increase up to the point of settling as could be accomplished in an even and regular manner. That seemed to have been our fetish—"no matter how rapid, if it was done in an even and uniform manner, it must be all right." We had yet to learn that uniformity was not the whole secret and that some stages of the kiln operation could be carried on at a very much more rapid rate than others. To this end the schedule was changed from the chart shown in Table II to the one shown by Table IV. It was by following the Table IV schedule that bad results were obtained; the forced firing, following immediately

TABLE IV
SIX-DAY BURNING SCHEDULE

Hrs.	Period	Fires	Fur. doors	Settle
6	12	4 shovels	Open	After only 3 days drying, this was too fast an increase
12				
18	12	4 shovels	Half open	
24				
30	18	4 shovels	4″ open	
36				
42				
48	18	4 shovels	2″ open	
54				
60				
66	24	Heavy—so as to reach settling heat	Closed	
72				
78				Settle starts
84				
90	60 Hrs.	According to settle	Worked according to settle	
96				1″
102				
108				2″
114				
120				2″
126				
132				2″
138				
144				2″



Average Temperature Curve, taken from Pyrometer Charts of several Burns
Top and bottom readings shown.

after the kiln was dry, was entirely too fast and quashed, and shaky brick were the result. Our diagnosis was "heating up too fast."

The schedule was then changed, and the kiln was given a slower rate of increase for the first few watches and then a faster rate taken after the lower peep-hole became dull red. We found that it was impossible to do this and complete the burning in six days, so a seven-day schedule was adopted. We also found that time could be saved and good results obtained by holding the exhauster on as long as possible, for another 18 to 24 hours, or until it became so hot that it was absolutely necessary to take it off to keep it from being destroyed.

Examining the chart, which shows an average of the temperature increase of several kilns recently dried and burned, it must be evident from the temperatures shown, that most of the upper courses of brick have gone through, not only the drying but also the water-smoking process, long before the third and fourth days are reached: either that, or else there is a terrific thermal lag between the kiln temperature and the temperature of the interior of the ware.

Conclusions

In drying the kilns as rapidly as is shown by the chart, it can not be maintained that there is not a considerable lag in temperature; however it can be maintained that this lag is not great enough to damage the structure of the brick, from the simple fact that the brick were sound and with clear metallic ring.

The first theory mentioned above, then, must hold true; or as expressed in one of the early paragraphs of this paper, the various processes do not occur separately and distinctly in relation to the whole body of ware but commencing at the point nearest the source of heat, they follow one another consecutively, the one gradually merging into the next as the temperature increases.

Certainly the writer's experience coincides with Geller's conclusions, that is, that more rapid and safer water smoking can be accomplished with induced draft. In our case, the induced draft was used primarily as an aid to drying. The brick were in the kiln in which they were to be burned, and, as a consequence, the whole kiln structure was heated as the drying progressed: also the stack draft was established. If it was of benefit, under these conditions, how much more beneficial induced draft might be where brick, even thoroughly dried, are placed in a cold kiln and the fires lighted with draft currents, negative or reversed, can only be surmised.

In conclusion, the writer's experience would indicate that a light portable exhauster, arranged for easy attachment to kiln or to the tunnel between the kiln and stack, would prove economical in many plants.

Discussion

Mr. W. W. ITTNER:—I have seen a good many articles, but I have not seen anything that struck me so forcibly as this article of Geller's applying to the manufacture of brick. Most of the articles and most of our efforts, I think, have applied to the higher branches, glass and pottery and that sort of thing, and it reminds me that we can have so many leaves on the trees as not to be able to see the foliage, and things get by us. We do not see the squirrels, for instance, but I think I have a squirrel here.

Geller speaks about dry press ware having to be handled much more carefully than other kinds. I do not know whether our clay dries exceptionally easy or not, but we have not had any difficulty whatever in drying and my experience (with different clays) is that dry press wares, do not show any particular difficulty in drying. In talks with other people, I find that that experience is more or less borne out.

Mr. TEFFT:—I want to thank Mr. Ittner for this paper because he at first did not think he had enough to talk about, but I personally believe "Water Smoking with Induced Draft" is one of the big things we are all going to come to.

A MEMBER:—What size fan did you use?

Mr. ITTNER:—What they call a No. 80. About thirty-inch intake and about a twenty-four inch discharge. Its maximum speed was about three hundred and fifty revolutions.

Mr. TEFFT:—What was your finishing temperature of the burn?

Mr. ITTNER:—We started settling at about 1700°, and 1775° is about a finishing temperature.

Mr. TEFFT:—I was asking that for the reason you gave the burning time as seven days. Did you make an attempt to put the exhaust gases into the chimney?

Mr. ITTNER:—No, the fan discharges right into the air. The kilns were all in line, eight kilns.

It is really remarkable the saving in time accomplished by this method. The only thing that would make other results differ from ours is that our kilns were old and they did not have sufficient grate surfaces. The earlier kiln designers did not know what adequate grate surface was. Later kilns have almost twice as much grate surface as we have.

A MEMBER:—What size motor did you have?

Mr. ITTNER:—It was an engine. An engine-driven fan is a pretty expensive proposition.

Mr. TEFFT:—At our Darlington Plant we are burning face brick entirely with induced draft, having no chimneys or stacks but discharge the gases from the burning kilns direct into the open. Our brick is made from a No. 2 grade of fire clay that finishes at cone 10. We are getting this cone down in the top of the kiln and are getting cone 8 down in the bottom of the kiln, the kilns being set on edge 34 brick high. The brick made are of a high grade buff and manganese gray of face brick quality. They are being burned in six days' time and we run very close to this schedule at all times because of the draft system in use. This system does not vary from day to day or from summer to winter but is constant and we can control the draft in our kilns almost at will. We are shading our brick to a close shade and it is quite often that we get as high as 75% one shade on a smooth speck brick.

A MEMBER:—Do you use a drier?

Mr. TEFFT:—Yes, we use a drier. This drier receives its heat from radiation obtained from cast iron pipes running underneath each drier track. These pipes are a continuation of the main flue which supplies draft to our kilns—that is, the fan supplying draft to the kilns is put on the cold end of the drier and all combustion gases are pulled from the kilns through the main underground ducts to the hot end of the drier where they enter cast iron pipes and are pulled through these pipes underneath the drier cars and by radiation from these pipes we are able to dry our brick very successfully. The discharge gases from the fan pulling these gases underneath the drier tracks are quite uniform in temperature, being 320°F.

A MEMBER:—Do you have a fan between your kiln and the drier?

Mr. TEFFT:—No. The kiln is between the flue and the fan. The burning gases do not come in contact with the brick in any case.

A MEMBER:—Doesn't the sulphur in the coal eat up the fan?

Mr. TEFFT:—We have had a fan for six years and no trouble.

A MEMBER:—Do you burn with coal or gas?

Mr. TEFFT:—Both, mostly with gas—natural gas.

A MEMBER:—You are using cast iron pipe?

Mr. TEFFT:—Yes, sir, cast iron bell-joint pipe.

TERRA COTTA PROBLEMS SUGGESTED FOR DISCUSSION AND INVESTIGATION[1]

By C. W. Hill

ABSTRACT

An occasional review of the manufacturing problems of any industry regarding which positive information is fragmentary or lacking is often of value. Such a review of some of our terra cotta problems may be productive of discussion which will bring to light unpublished data and may inspire our industrial ceramists to increased activity in fundamental research. It may also be of value to our University friends who are frequently in search of research problems of a practical nature. Naturally any summary prepared by an individual will not be complete but the omission of points which others regard as important will usually be noted and supplied by discussion.

The following subjects are proposed for discussion and investigation:

I. Plaster
II. Materials: (*a*) Body mix and materials, (*b*) barytes, (*c*) grog
III. Glaze
IV. Process
V. Patching
VI. Service problems.

I. Plaster of Paris

Since plaster of Paris does not enter into the body or glaze and hence does not directly influence the ware, it apparently has not received much attention from terra cotta ceramists. The tendency has been to require plaster manufacturers to supply a quality of plaster which will satisfy the workers and the foreman. The standards of the A. S. T. M. are not especially applicable to plaster for our use. A complete set of specifications based on actual tests would be of value to the industry. It is, of course, necessary to bear in mind that local shop conditions influence the qualities desired in plaster. The setting time may differ between a shop having piece work systems and one paying by the hour, or between one in which a moulder works on one mould at a time and one in which he carries several moulds at once. The relation of physical properties, as shown by tests, and the strength, absorption, warping and chipping of moulds has apparently not been established. The selection of the best possible plaster, considering cost of plaster, volume of set plaster per pound, efficiency in use, cost of repairs, and life of moulds would doubtless effect a considerable saving to a factory during a year.

The possibility of adding agents to plaster so as to increase the rate or extent of absorption of moisture from the clay without undue decrease in mould strength is a most interesting subject for investigation.

The development of proper apparatus for uniform gauging of plaster and the supply of gauged plaster to the worker, while largely a mechanical problem, is one which requires a familiarity with ceramic problems. It would seem to be a matter quite promising of practical results.

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[1] Read before the Terra Cotta Division, St. Louis, Mo., Feb. 28, 1922.

At present costs the question of recovery of used plaster is one of commercial value when several plants are located fairly close together. Theoretically, there is no reason why the plaster can not be recovered. It should be possible to do this on a commercial basis provided enough waste plaster is available in a locality to warrant the cost of the installation. It would apparently not be profitable for any individual plant. Some efforts to reclaim plaster have been described in the literature, the common result being a plaster of low strength due to the presence of a high percentage of anhydrous sulphate. A careful study of vapor pressure would indicate the requirements of a suitable process. These processes may be outlined qualitatively as a means of heating a mass of plaster to the desired temperature for conversion without loss of moisture, removal of moisture under control and cooling under control. The fineness of the product would require the same attention as in the manufacture of new plaster. Deviations in properties of recovered plaster could probably be compensated by mixing before use with a suitably selected fresh plaster. The commercial possibilities of the process are, of course, related to the price for new plaster, freight rates, cost of coal and availability of a sufficient quantity of waste plaster in the locality.

II. Body Mix and Materials

The subject of body mixtures and materials has, of course, been studied by each plant as dictated by its available clays and the plant equipment and process. The relation of body composition to strength, porosity, expansion, etc., is being made the subject of investigation by the Bureau of Standards with the coöperation of the National Society and need not be discussed here. There remain, however, certain points of general interest which merit investigation.

Barytes.—Many manufacturers of ceramic products have found it necessary to add barytes to fix the large amount of soluble salts in their clays. Others, who have but small amounts of soluble salts, add barytes to be on the safe side, without having determined the efficacy of the addition or the amount required. Some are knowingly adding barytes in excess since it is rather difficult to watch the amount of soluble sulphates and any great increase might not be detected until quite a tonnage of ware was pressed and in the dryers.

Some manufacturers purchase barytes on specifications based on chemical analysis while others make only a qualitative test. Chemical tests of barytes are not sufficient guides for purchase for the reason that the activity of the barytes is not entirely dependent on its purity. The fineness and method of preparation influence the extent to which it will react with soluble sulphates. The effectiveness of barytes is extremely doubtful in cases of low concentration of sulphates. The percentage of sulphates necessary to give rise to trouble has not been established. Some of these points have been investigated in our laboratory and will be made the subject of a larger paper when the work has been completed. The indications are that a considerable amount of money is being spent for barytes unnecessarily.

M. E. Gates[1] has discussed the use of barium hydroxide in place of barium carbonate. While the superiority of the hydroxide can hardly be doubted, the point was not established experimentally in Mr. Gates' paper which dealt primarily with a suitable apparatus for the use of hydroxide.

Grog.—The investigations of Clare and Albery[2] have shown the importance of further work on the nature of the grog and of the use of grog of controlled sizing. Additional investigation should, if possible, have results expressed quantitatively in terms of physical properties of the body as well as qualitatively in factory terminology. Some assistance on the problem may be anticipated from the work now in progress at the Bureau of Standards.

Wilson[3] has suggested the further investigation of grog sizing particularly with reference to slip cracking.

Davis[4] in an admirable paper has shown the effects of using grog of definite screen size and suggests the study of grists.

Flux.—The tightening of the body by additions of suitable fluxing agents is an interesting field for investigation. The subject will be discussed later, since papers on this subject have been promised.

III. Glaze

Investigations on terra cotta glazes have been extensive but the reports as published unfortunately do not as a rule present sufficient data to permit of duplication or of practical use. This is due largely to the failure to give the chemical analysis of feldspar used or to express formulae in the accepted XRO, Al_2O_3 Y SiO_2 manner. In some cases the expression has been given in this form but the feldspar has been calculated to the theoretical feldspar formula. It is common knowledge that even feldspar from the same mine varies sufficiently in content of free silica and in alkali content and ratio as to make the direct substitution of material from one carload for that from another shipment impossible. It is commended to the attention of our writers and editors that papers on glaze should contain chemical analyses of feldspar and that glaze formulae should be expressed on a common basis. This will be a decided advantage although it will not tell us all that we should know, since the chemical analysis does not indicate the amount of free SiO_2 as distinguished from that which is combined.

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[1] Gates, M. E., *Jour. Amer. Ceram. Soc.*, **3**, 313 (1920).

[2] Clare, R. L., and Albery, D. F., *Ibid.*, **3**, 384 (1920).

[3] Wilson, Hewitt, *Ibid.*, **3**, 114 (1920).

[4] Davis, H. E., *Ibid.*, **3**, 641 (1920).

Tenacity.—The subject of glaze tenacity and of the degree of penetration or union with the underslip or body are all of great importance. The microscopic method is the common method of attack and while it is productive of a great amount of information it is unsatisfactory in many respects. On account of the apparatus required this is a subject for university research along physical as well as chemical lines. Undoubtedly the use of underslip renders the problem more difficult and probably tends to lower glaze adherence.

IV. Processes

The processes of mixing, ageing, forming and drying are well understood in a practical way. While our information could be increased by further research it would seem that other manufacturing problems are more pressing.

The burning presents many problems of both theoretical and practical value. One of the most important is the determination of the critical cooling ranges of the burned ware. While these may vary somewhat with the different bodies it is quite probable that bodies maturing at the same temperature will have approximately the same characteristics in this respect, assuming no great difference in tightness of body. Doubtless our product may be cooled rapidly through certain ranges while in other zones the cooling must be slow or dunting will follow.

Hill[1] has discussed the results of Purdy and Boeck and has suggested 650°–500°C as the critical zone, more as a result of deduction than that of experimentation with a typical terra cotta body. With periodic kilns the point is not as important as with tunnel kilns in which full advantage may be obtained of rapid cooling. The use of tunnel kilns will doubtless bring out the critical ranges as a result of long experience and operation, but the ranges could be determined experimentally much quicker and at lower cost. R. L. Clare[2] has done some work which leads him to favor a tempering of the ware.

On account of the relatively small amount of free silica present in the body it is not to be anticipated that changes due to the transition of silica from one form to the other plays an important rôle. Likewise the analogy which some investigators have attempted to draw between clay ware and glass is extremely doubtful since the similarity of the bond to glass (a homogeneous solid solution) is probably masked by other factors. However, it is recognized in all plastic compositions that the characteristics of the bonding material frequently influence the properties of the mass far beyond the proportion which the bond bears to the mass of the inert constituents. These speculations would lead to a study of the characteristics of the bond and inert material separately as well as those of two variables together.

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[1] *New Jersey Ceramist,* **1,** 73 (1921).

[2] Private communication.

Considerably more research and engineering is required on tunnel kilns before they may be acclaimed a success for terra cotta. It would seem that better and less expensive types than the muffle tunnel kiln are commercially possible. This may be seen by the following considerations.

The rôle of the muffle in our intermittent kilns is largely that of protection against flame and ash. A muffle also offers a partial protection against the reducing gases. On account of the fact that all commercial refractories when hot are permeable by gases, there is a tendency for all flue gases to diffuse into the muffle. Usually there is sufficient access of air to the muffle to oxidize the CO and hydrocarbons and to prevent the reducing action of SO_2. SO_2 is usually present in a muffle during the certain parts of the burn and although it may issue from the parts in concentration sufficiently to be stifling, it does not do harm to the glaze as long as oxygen is present. With the usual design and operation of kilns the diffusion through the muffle free from leaks is not in excess of the amount which can be oxidized by air drawn into the muffle, except during the latter part of the burn when CO is frequently found in percentages as high as 0.2%. Ortman[1] reports as high as 1.6% but this could hardly have been obtained under good conditions.

This leads naturally to the assumption that terra cotta can be burned without a muffle, provided it it protected from flame and ash and that the flue gases which come in contact with it are the products of complete combustion with a slight excess of air. These conditions are found in the surface combustion type of furnace. A wide variety of slips and glazes were fired in a surface combustion kiln, the fuel being city gas. It was found that the colors were exact duplicates of similar burns in a muffle kiln. A further test was made using unpurified producer gas from anthracite coal, care being taken to insure an excess of oxygen. It was found that the SO_2 under these conditions had no effect on the glazes or slips. Among the slips and glazes tested were several containing iron oxide which had been found to be somewhat sensitive to improper kiln conditions.

A kiln of the surface combustion type would possess the advantages of simple construction with comparative low cost, and should be more efficient since the ware receives the heat directly without the interpolation of the muffle. The absence of the muffle should result in a shorter kiln and less difficulty from overlapping of temperature zones. It is to be expected that a kiln of this type should give less fire-cracking since the heat is transmitted to the ware by convection of the burned gases instead of radiation from the muffle and is taken away in cooling in a similar manner. The temperature gradient within the piece is therefore much less than when it is heated by radiation and, by proper design and control the gradient between the flue gases and the ware can be made quite long.

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[1] *Jour. Amer. Ceram. Soc.*, **3**, 487 (1920).

Theory and experiment, therefore, point to the possibility of burning terra cotta in a tunnel kiln without a muffle and with results not to be expected in a muffle kiln. While other means of securing complete combustion without flame may be possible of development, that of surface combustion is the only one with which the writer is familiar. The adaptability of the system to large sized chambers has been proved in other lines of work as well as the absolute control and constancy of the kiln atmosphere.

The preliminary results of trials with surface combustion kilns for terra cotta are sufficiently encouraging to warrant a most careful investigation by the individual manufacturers before going ahead with the muffle type of tunnel kiln.

The installation cost appears to be about 50% more than that for intermittent kilns of the same capacity and not more than half that of the muffle type of tunnel kiln. The labor cost of operation should be about the same as the muffle tunnel kiln, burning the same fuel, whereas the efficiency from a thermal-time standpoint should be much higher. On account of the lower temperatures and absence of flame the life of the simple refractory shapes should be very long indeed. The repair should be a comparatively simple and inexpensive matter.

Patching.—The repair of pieces scarred or chipped in shipping where mechanical strength of the piece is not impaired or where there is no danger from the infiltration of water when placed in the building, is a matter frequently of saving an expensive piece of ware. The development of a completely satisfactory cement would be of great value to the industry. The requirements are that the cement be capable of use by the average artisan, and that it have permanency of strength and color. Many cements change color on weathering, making an unsightly blemish on the piece. It may not be amiss to appeal to all terra cotta ceramists to publish their investigations on patching cements. It is quite probable that some manufacturers have developed a better cement than others and are inclined to regard the information as a trade or company secret, not realizing that the use of an inferior cement by any company injures the business of all companies. As a research matter the application of dental cements to this purpose offers a very attractive field. A complete survey with comparative tests of all the cements given in the literature for ceramic ware or stone, and those now in the market would constitute a valuable contribution to our section.

V. Service Problems

The effect of lime and other components, method of preparation and application on the permeability, shrinkage, and strength of cements used for setting terra cotta is a subject of vital importance to the industry. While much can be done by proper construction and by the use of flashing for exposed work, the joints still afford a means for the introduction of water into a terra cotta wall and a large percentage of the failures attributed to terra cotta have been due to the admission of water through poor mortar. Although it might be said that research along this line is not within our field it is certain that investigation is needed and that we are all as much interested in knowing what is the best mortar obtainable as any one else can possibly be.

Along the same line it should be noted that many terra cotta manufacturers are still showing construction details which cannot fail to give trouble from the introduction of moisture. The chemist can be of assistance to his company by emphasizing the need of protecting iron from corrosion and the danger of cracking of terra cotta due to the expansive force of rusting iron imbedded in terra cotta which may become moist.

Atlantic Terra Cotta Co.
Perth Amboy, N. J.

MANUFACTURING CLAY PRODUCTS 14,000 FEET ABOVE SEA LEVEL[1]

By E. O. King

ABSTRACT

A description of the clays and methods employed by an American mining and smelting company in the Andes Mountains for the manufacture of common and refractory brick.

Several of the large American mining and smelting companies in South America operate their own brick plants because the transportation of ceramic products from the United States requires much time and the losses due to breakage from handling en route are very heavy. Brick shipped from the States must be carefully packed in heavy cases or barrels in order to withstand the rough handling which they undergo in oceanic shipping. From date of requisition to time of delivery usually means a period of three to six months. Upon arrival at their port they are loaded into lighters and taken ashore. Native transportation from the coast to the smelters in the mountains is a slow and costly proposition. Quite often the purchaser finds upon unpacking his material that part of it is of inferior quality which probably failed to pass inspection for home trade. With these problems to contend with the various companies have found it more satisfactory and economical to manufacture the majority of their requirements from local materials.

One of the above mentioned companies successfully operates its own plant in the Junin District of Peru at an altitude of 14,300 feet. This plant, originally built for the manufacture of common brick, was later converted to produce fire brick and silica brick. No definite capacity is maintained, the output being governed entirely by general construction and smelter requirements.

The equipment now consists of a jaw crusher, crushing rolls, two eight foot wet pans, a steam heated rack dryer and power repress. A small shaft lime kiln and four round down draft kilns—two 27 feet and two 30 feet in diameter—equipped to burn either coal or oil complete the layout.

The class of labor available in this section is the "cholo" Indian. They are a low type mentally and seem quite incapable of grasping the duties attached to more than one job at a time. Having learned a job they will stick to it and perform the duties in a mechanical way until removed. Little labor trouble is experienced and the turnover is very small year in and year out.

Common Brick.—The average deposit of common clay in this section contains lime in such quantity as to render it unfit for brick manufacture. The workable clays are found on the sloping pampas where natural weathering has removed the lime. These deposits are lean, sandy and carry large quantities of small quartzite particles.

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[1] St. Louis Meeting, Feb., 1922.

This clay is ground in wet pans and then hand moulded by the soft mud process. After drying the brick are burned in down draft kilns, coal being used as fuel.

Modern stiff mud machinery was installed on a new construction job with the intention of using this same type of material. The clay being very short made it impossible to form a proper column and the brick were very tender to handle. Wear on the die liners and auger tip was excessive, these parts being completely worn out before 200,000 brick had been run. Burning in updraft kilns with coal proved unsuccessful since cold air admitted to the arches during cleaning period chilled the rocky content so that the resultant product was weak and spongy. To eliminate the cleaning periods oil burners were installed and a fair product was obtained. Recently other deposits, free from the rocky particles, were discovered and are being worked successfully by the stiff mud process.

Fire Brick.—The fire clays of this section are found at an altitude between 10,000 and 11,000 feet in a vicinity of the coal mines. These are of the semi-plastic variety and contain sulphur. The veins, with low sulphur content, are mined for the manufacture of brick. This material is hauled over the company's railroad to the plant and stored in piles where it is allowed to weather. The warm tropical sunshine of the day followed by freezing temperature at night causes the material to weather rapidly and the iron oxides and sulphides present are dissociated and driven off in a short time. The material used for brick has the following analysis:

SiO_2	57.60
Al_2O_3	26.88
Fe_2O_3	0.40
CaO	1.24
MgO	0.14
Loss	13.74

This clay is put into the wet pans direct and grog added in the form of crushed burned bats. After the desired plasticity has been obtained the mud is wheeled to moulding tables where nine-inch straights and the nine-inch series are moulded. The brick are put in the dryer for a short time and then repressed. Shapes are avoided whenever possible since this material is unsuitable for their manufacture. Circular bench setting with a four-inch space between benches proved to be the most successful method with the class of labor available since by using other methods the men neglected to leave sufficient draft space for proper heat distribution. Coal is used during the first stages of the burn but to obtain the finishing temperature of cone 5 oil is used. The available coal is a very low grade and suitable only for finishing common brick.

The brick produced from this clay are light brown in color with a fairly porous structure. They undergo but little volume change at medium temperatures and are well adapted for roaster linings, hearths and furnaces where a first class fire brick is not required.

Silica Brick.—The quartzite used for brick manufacture is grayish white in color and consists of medium sized grains of silica cemented tightly together by a silica matrix. These deposits are located at an altitude of 15,000 feet and about six miles from the railroad.

Contracts are let to the natives for the mining and transportation of this material to the plant. The rock is broken into lumps not exceeding six inches in diameter and packed in sacks of about 100 pounds each. Llamas are used for carrying these to the plant and one sack constitutes a load for an animal. These animals are very sensitive to the load which they will carry and it is claimed that if the burden exceeds one hundred pounds very much that they will kneel and refuse to move until the load is lightened. The quartzite unloaded at the plant cost about $2.75 per ton.

An average analysis is as follows:

SiO_2	96.96
Al_2O_3	1.12
Fe_2O_3	0.80
CaO	1.02
MgO	0.10

The quartzite must be sorted and washed before being used in brick manufacture since the contractors do not always reject the inferior grades. Low grade rock is set aside to be ground for locomotive sand. The selected material is broken down in a jaw crusher and then crushed through rolls. From here it is passed over a quarter-inch mesh screen and the fines are placed in wet pans for further grinding. Preliminary crushing and screening is necessary since the pans are of light structure and not suitable for heavy grinding. The batch is moistened and given a short grind before the addition of lime. Lime varying from 1.5 to 2 per cent of the weight of the quartzite is mixed in troughs and added in the form of a slip. The grinding is continued until the desired fineness is obtained. Shapes for reverberatory furnaces and nine-inch brick are moulded with no difficulty.

The lime used is burned at the plant since any quantity of limestone high in calcium carbonate and low in magnesia content is available in the surrounding country.

The same method of setting, as used with the fire brick, is followed and for burning coal and oil is used. The brick are burned to cone 16 and this heat held for 36 hours before closing. They have been unable to secure higher finishing temperatures for silica brick in these kilns since they were designed originally for burning common brick. At this altitude it is necessary to increase flue sections about $33^1/_3$ per cent in order to gain sufficient draft for proper fuel consumption.

The first practices employed on this plant were the old "rule of thumb" methods introduced by men who had learned them after years of hard experience. They served their purpose for the time being but during the past few years the company has recognized the value and necessity of applying the most modern methods for producing the best ware with the materials available. A new plant is being constructed, under the guidance of a technically trained man, which will contain all modern machinery and mechanical equipment necessary for the production of first class refractories.

American Refractories Co.
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ORIGINAL PAPERS

CERAMIC ART AND ARCHITECTURE[1]

By GABRIEL FERRAND

I did not want to miss this occasion to instruct myself, of the progress made in American pottery; and secondly, of the possibilities offered by American ceramics in the field of architecture. There are two kinds of terra cotta, one for exterior and the other for interior use and I shall take these up respectively after we have completed a brief review of the uses of terra cotta during the past centuries.

Since a very early time the art of pottery, or ceramics, was applied in a number of ways to great advantage. Assyrian and Babylonian civilizations have left us some wonderful examples of the application of terra cotta and colored glazed brick to produce a monumental effect in architecture. We also know that in Persia and other Asiatic countries many a mosque, palace or mausoleum has been decorated with tile, the color of which is very beautiful. Reproductions of these works are well known. Suffice it to mention one example that is known by everyone, namely, the Taj Mahal.

Then we were shown some examples of pottery belonging to Chinese art. In China, mausoleums and temples, as well as palaces, were decorated with a sort of an antefix much similar to that of the Greek, always placed on top of the roofs of tombs and structures protecting Chinese graves. This kind of pottery or ceramics is the very kind applicable to architecture.

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[1] Address delivered before the Art Division of the American Ceramic Society on March 1st, St. Louis Meeting.

The Greeks and Romans, in turn, used terra cotta, and we saw some interesting illustrations of that use, but in Europe we have to come to the early Italian Renaissance to find such use of ceramics greatly enlarged through the genius of the Della Robbias. They knew how to handle clay, and the Italian architects of their time knew how to apply it to their buildings. In fact, it is in that part of Europe that the foundation for extensive use of terra cotta was laid, and the Italian name which means "baked earth" is so expressive of the nature of this material that it has passed through Italy to us and probably will be used forever.

Terra cotta in Italy is applied in a very interesting manner. May I recall those beautiful churches such as are found in Florence, Fiesole, Bologna, etc., and especially that admirable Certosa in Pavia. Many people have no idea of the charm that is found in Italian towns and cities where large buildings as well as small structures are decorated with glazed and colored terra cotta. It is, indeed, quite a refreshing and welcome change from the aristocratic elegance of marble or stone, or the simplicity of brick, and there is no doubt in my mind about the great future of terra cotta in architecture.

We also find splendid examples in Spain of the Moorish architecture. I may mention the Alhambra, the Alcazar and the Generalife, or the cities of Granada, Cordova or Seville that will suggest a splendid display of color to be seen, not only in Spain, but in Northern Africa as well, where the application of colored and glazed tile is found in practically every building of importance built by the Moor or the Spaniard.

We now come to modern times, I mean to the last three centuries which are nearest to our present age. We admire works of Bernard Palissy, one of the greatest, if not the greatest, among French potters, and one who sacrificed everything for art's sake and whose name will forever star in the history of ceramics. There is, however, one period of which perhaps few of us know. We all have heard about Versailles, but besides the Chateau itself, there exists two other smaller structures called respectively The "Grand" and "Petit" Trianon. Before the erection of the Grand Trianon there was in the same spot another Trianon called the Trianon de Porcelaine, erected by the King of France, Louis XIV, for Madame de Montespan. As the name implies it was a structure made of brick entirely covered from the ground to the top with porcelain panels and tiles, glazed and colored. One of the contemporary writers tells us that "when one enters the garden one can view it, all covered with faience works, porcelain urns and vases of various kinds which produce an effect unique in the world." This effect was chiefly produced with two colors, the white and the blue, with touches of gold. The vases were also white and blue, Chinese fashion, and even the boxes containing orange or laurel trees were decorated with white and blue paint, to harmonize with the porcelain itself, fragments of which still exist in the Versailles Museum. This building, which, if we believe the descriptions made of it, was one of the marvels of that period, was demolished to satisfy the whim of the king. The wishes and fancies of those monarchs were so ever-changing, that when any building had ceased to please them, they simply called on their architects to build something else, regardless of cost.

This procedure, however, seems responsible for some of the finest masterpieces that have been preserved to the present day. If it were not for the lavish expenditures made to satisfy the fancies of kings and potentates, we could not admire today those resplendent works because they would never have been built. Kings have disappeared and democracies have taken their places. One would believe that with the advent of the republican form of government, such gorgeous structures could not be possible. But, we again find splendid modern examples of the use of terra cotta in monumental edifices built during the first year of this 20th century. There is a lapse of about 150 years between the Trianon de Porcelaine and the International Exposition of 1900 in Paris, but it is nevertheless gratifying to see that the use of terra cotta has been revived on a large scale. We shall recall, briefly, what happened at that time. The French architects, appreciative of the splendid effects obtained in the past by their predecessors, decided that they had a unique opportunity to make use of terra cotta on an extensive scale in monumental architecture, and especially in two of the exposition buildings, facing one another called respectively the Grand and Petit Palais. The Grand Palais, however, is the one which presents the most pleasing decorative effect with two large friezes, illustrating some episodes of the history of France or the city of Paris. One of these friezes is unprotected and laid on the outer surface of the wall entirely exposed to the elements, while the second is found under a portico affording ample and adequate shelter. No better example of the modern use of terra cotta could present us with that sort of directive for the future we so much need. When these palaces were built and especially the larger of the two, every architect, every citizen of Paris and France was interested in the attempt which was not, indeed, new to French architects, but still looked on as a new venture in that field. I saw these works when started and saw them when completed. They have fully produced the results which were expected, and they present that very touch of color which breaks the whiteness and monotony of the stone, however beautiful the stone may be in France.

There were also other examples of a purely decorative nature. I shall only mention a fountain made of Sevres ceramic which has been preserved and is at present decorating a party wall facing the garden of the church of Saint Germain-des-Pres. Besides, there are the façades of many a plebeian apartment building, for the decoration of which the potter and the ceramist had to contribute their best talent.

I stated a while ago that we have two uses or two different manners of using pottery or terra cotta, one for building exteriors and the other for interiors, and each calls for a different kind of material. To be more precise, we should say that the effect of color, to be satisfactory, must differ for both, and this for obvious reasons. We all know that color placed outside will fade when exposed to sunlight or at least appears lighter. No better example can be found than that of the painter who, in his studio, depicts sunlight atmosphere such as in a sunset or sunrise scene. He has seen magnificent coloring which he tries to reproduce on his canvas. When through with his work, let us assume he is quite satisfied with it and congratulates himself. Then he takes it out of doors and looks at it under the sunshine, but to his great surprise it has faded away and those colors that looked so gorgeous and, perhaps, riotous in the studio, are absolutely gone. This is the very change in values of coloring we have to remember.

I am speaking from the viewpoint of the architect and not touching upon the technical phase of ceramics, because if I must confess I know so little about either the technical or the chemical sides of this subject, I am, however, cognizant of the main principles of pottery and realize the opportunities which are offered through the use of ceramic products. These I want to emphasize and should like to tell members of the American Institute of Architects that too often the cause of some of our failures is that we all are too conservative and do not dare enough. Architects, are too opposed to change or progress.

We know that we may appeal to ceramists to provide us with fine work to put on our façades, but we also know that if we do not take the initiative you can not well be given the opportunity for such fine work. We are to conceive and you to execute. We are to be, to an extent, the directors of your work, but we must first ask you what can be done. There are limitations in your field, as well as in architecture or any other human enterprise. It is only the craftsman or the artist, experimenting constantly with his materials and his colors, who fully knows their possibilities and their limitations, what colors are fast and ought to be used, or what others will fade and should be discarded. The architect, therefore, comes to you and asks advice on that subject, but you must rely on him for general design and color effect.

The use of terra cotta is susceptible of many varied expressions. It may be used as friezes or as panels, or in a number of different applications. The Babylonians used them extensively as friezes of large figures, beautifully treated in a very bold manner. They were of such large scale as would permit of viewing them at a great distance. They never were lost in the general design on account of smallness of details or minuteness of the elements that enter into their composition. Splendid examples of decorative scale were they. *Scale* is the most difficult of all the requirements of good composition and is very often misused or misunderstood. It should vary according to its use, as interiors are different from exteriors. But we must not forget that however beautiful and to the point a detail might look on the inside, it will be lost on the outside. We all appreciate the importance of scale in architecture, and most especially in its relation to the human figure and the average distance that will exist between the object and the onlooker's eye. We should never forget these variations.

The architect who wants to use pottery or terra cotta will come to you with some requirements or specifications, as he does for any other building material. What ought to be these specifications? What ought to be these paramount requirements?

The first should be one of *durability*, essential to every lasting material. It is up to you to find such material as will defy time, as will stand untouched by the destructive action of the elements. The answer to this requirement is plainly up to the potter and the ceramist; not to the architect.

The second requirement would concern *color*. To provide for the color which will enable the architect to make his dreams become true is again a matter for the potter, or rather for the chemist working side by side with him. The different colors used should be fast and unchanging, and should harmonize with the other materials used in the building. Here we may take our lessons from the past and try to emulate what the Oriental, the Greek, the Arab, the Italian, and others have done in that field. If we use stone or brick the color of our terra cotta will have to be either in contrast with the background or in harmony with it. It is wholly up to you to advise the architect as to what possibilities terra cotta, either mat or glazed, may offer and show him such samples as will enable him to select the color that will produce the desired effect, and as can accurately be reproduced in the finished product.

The third requirement, and perhaps not the least, is that of *cost*. Up to the present time this cost has proved to be, in many cases, a great stumbling stone. If it were possible to obtain on a commercial scale terra cotta of a beautiful nature, for I have always in mind quality as well as quantity, if it were possible to obtain splendid medallions, at reasonable prices, (and please notice I do not say moderate but reasonable), there is no question but that the future use of colored terra cotta in architecture would be fully insured. It would be very bright and I am convinced it would not take long for the people to get so enthusiastic about its use as to see it soon become a fad. This we ought to avoid. It certainly should not become a fad, but only a logical and sensible application of a beautiful material for the greatest benefit of architectural expression.

Among the samples exhibited at the St. Louis meeting there were some clever tricks played in terra cotta. There were fine imitations of granite, marble and other materials. I certainly am not in sympathy with such uses. Why should terra cotta, which possesses such a wonderful plasticity, try to become a mere imitation of other materials which do not possess it? Why make it so closely to resemble marble, which is altogether a different material and can not be imitated, at least in that way? Why force it so accurately to imitate granite that at a distance the substitution can not be detected by the eye? Deceit in art has never been successful for a long time. We remember how strongly Ruskin condemned it. Although I do not accept to every statement Ruskin made about architecture, because their strict application would prevent some of the progress made in this century, I am satisfied to subscribe to that special statement of his so far as it concerns terra cotta. In trying to deceive, terra cotta is entering into a channel for which it is not intended and for which it is not made. The field of its application is large enough without trying to make it, as we might say, "play second fiddle," while it can most successfully play first.

Another matter to be considered is that although the architect is beginning to realize the decorative value of colored terra cotta in some parts of the country, he has not yet done so in this middle west. Only few attempts, and very timid ones, have been made and this is to be regretted. I have seen so many beautiful examples in the old world that I am wondering why, in this new world, so replete with opportunities of all kinds and where there exists such a large field for the application of terra cotta and pottery, the architect has not taken full advantage of these multitudinous opportunities. I said a while ago that the architect is, generally speaking, too conservative and his daring too limited. It seems to me that such conservatism has gone the same way as that of the peasant who, in order to economize, gradually cut down the food allowance of his donkey until it died. He could not understand why, since his donkey had been working until the very last minute and seemed to be getting used to starvation, it should die. I can not help but think of this when I see beautiful examples of a past, which we all so greatly admire, discarded by our present generation for a more conservative use of the materials. I have always been so lured by color, either used in monumental architecture or applied to more modest domestic buildings as to make me deeply regret that we architects of the present day are not taking more advantage of it. It looks as if the architect had by degrees eliminated its use until, on account of its total absence, most of our present buildings have become uniformly monotonous. And yet, nothing will more enhance the beauty of a stone or marble structure than color when judiciously located; not distributed everywhere, but only in a few selected spots where it will better contrast with the stone or the marble, so as to make it look more beautiful and more charming to the eye. It is what I hope every architect will realize in time. Then the day will come when, through the impulse your association will give to the application of colored terra cotta and its manifold possibilities, it will be used extensively by the members of our profession.

You can not, however, depend solely on the architect. Go to him and show him your productions, bore him, if I may say so, with your wares, annoy him to the point when, in order, to get rid of you, he will give you a chance. Then, after he has realized and seen what you can produce, I am confident he will be so pleased as never to stop using your material. This has been my very experience. After all, the architect ought to be a man of progressive ideas, always ready to try the use of those architectural elements that may enable him better to realize his conceptions and to express the creations of his mind.

School of Architecture
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Discussion

Mr. E. C. Hill:—I have been quite interested in Prof. Ferrand's address. I do not know whether I understood him about the fading of terra cotta when used for exterior purposes. I do not believe the color we make will fade other than as it becomes dirty.

Prof. Ferrand:—You know what colors can best be used for that kind of work, and that is the point I was trying to raise. It is, indeed, up to you to go to the architect and make him aware of the qualities of those colors. I know that here in St. Louis there have been a few attempts to use colored terra cotta for exterior purposes. In addition to a certain number of small structures we have the Moolah Temple, the house of the Shriners. Now I have often heard its architects say that they were somewhat disappointed because they could not get the very colors which would produce the intended effect as they expected.

It may happen that the architect will be unreasonable, though I know more thoroughly, perhaps, than you do what his limitations are. If he is unreasonable it is up to you to tell him frankly that his plans are not practical. It would be better than granting him anything he wants if it is not within reason.

Now, if you choose to withhold your practical advice you will find you can not live up to your promise. You also know that when unsatisfactorily colored parts come to the work and are erected, they are bound to disappoint the architect who most probably expected a better harmony of colors. I know very well that if you have colors which will not fade and are durable, the variety of those which are desirable for the decoration of exteriors is certainly limited.

Mr. Sheffield:—It is all very well to talk of architects and art in a meeting. I have noticed that the architects themselves, seem to get an entirely different atmosphere when they get together, and talk about their wonderful profession. They are somewhat different creatures however when you meet them in an office about business.

We have classified the architects, of today, in our office, as architects and "hashitects," and unfortunately, we have a great many "hashitects" to deal with, who insist upon certain things being done.

We also have limitations of the manufacturing establishment where we have to produce so much business a day in order to meet a large and growing pay roll. For thirty years our firm has been trying to preach these things mentioned in Prof. Ferrand's address. It is a good deal like the little peanut vender on the street, who says:

"We sella two things, da banan and peanut; all we make on da peanut, we lose on da banan."

Now we should like a little help. Our men are working all the time, trying to perfect their ware and their color, and the only thing we can say about the use of color is that we believe there is a great field for terra cotta in the United States in the use of color. But we hesitate to advocate it, for every time color has been used, the saddest thing about it is that it is fireproof and will last a long time.

Our work is condemned by the architect, when it is really his fault. We get very little sympathy from him. After working hard for months to perfect a color, or the texture that they want, they ask how much it is, and find that it is five per cent above Bedford stone, or some other material. They are very sorry that our material reflects the cost of taking pains.

However, we are gaining all the time, and we find that we not only have to educate our own men, but we also have to help educate the architect. So it is very difficult for a manufacturer to listen to these talks of idealism, even if I have a lot of it, myself. When I start to talk, they say,

"Behold, the dreamer cometh."

CHAIRMAN RHEAD:—We are going to dream, and we are going to work, but at the same time we are going to look for aid from the outside. When Prof. Ferrand finished his speech, I remembered a meeting we had in New York last year. I think it was at the Chemical Exposition. We invited J. Monroe Hewlett, who was president of the Architectural League at that time and if these two talks were compared they would be much alike. Mr. Hewlett used different words. He deplored the fact that while potters and terra cotta men had such a wonderful material available and so many wonderful possibilities, that all he succeeded in doing was to make a very bad imitation of granite. He rather exaggerated, but he expressed the same idea that Prof. Ferrand expressed. He was hoping, and suggesting, and advising that the terra cotta man use the full possibilities of this material.

It has been in my mind in regard to the American Ceramic Society that each time we have met for the last sixteen years we have talked about this matter and written about it, and have done an enormous amount of research work, but we have never had an exhibition. We have never shown what we were doing, not only among ourselves, but to the outsiders as well. By outsiders, I mean the architects and everyone else having some relation to the work of the terra cotta people, and people doing art work of any kind. It has been in my mind to show everything in some organized manner so that those interested may know something of the possibility of architectural terra cotta and faience.

I do not know how many terra cotta men are familiar with the Architectural League in New York, or how many are members of that organization. It is a most powerful architectural association, the most powerful in the country, and most of the leading men of this profession are members whether they live in New York or not.

This League has an annual exposition. At a recent meeting, there were two examples of architectural terra cotta exhibited.

MAJOR GATES:—I would like to ask Prof. Ferrand to explain a little more fully what he means by imitation of granite by terra cotta. Our old friend, Fritz Wagner, of the Northwestern Terra Cotta Company, once said:

"Simply because a combination of colors had been placed together before, was no reason why, when we made up a model sample of various colors, they should be called imitation."

Many architects do ask us to imitate granite, but we get so many different color effects in mottled surface, that I believe mottled is better than plain surface, and we do not think we are exactly imitating granite.

PROF. FERRAND:—Probably you do not knowingly imitate but you do so unwillingly. You are judged on results and not on intentions, which is quite different. I think that architects are often responsible for those "sins" if you let me so call them.

It is my privilege to educate young men in architecture, and I have found that the most difficult thing to do is to develop their imagination. If the architect had enough imagination, he could visualize at once the possibilities of colored terra cotta as a decorative element in architecture. But most architects are not naturally imaginative. They safely stick to the trodden path and do not want to go outside of it. They are satisfied with what has been done before. I certainly do not mean to speak against the architectural profession as a whole, or against the architect as an individual, but I am obliged to acknowledge facts. An architect once came to you and said he could not use granite on account of its cost and asked therefore if you could produce an equivalent for it. If he had never propounded the question you probably never would have thought of answering it by substituting terra cotta for granite. This particular architect should be held responsible for it. He should have come to you wishing to obtain some such expression of *terra cotta* as would be the decorative equivalent of granite and when asking for the proper name this name should have suggested some sort of terra cotta, or be any new name you might have chosen for it, but a name which would not confuse it with granite. It is not granite and never will be.

There is no matter of greater import than the education of the architect. That education presents a difficult problem, too often solved unsatisfactorily. Let us consider that an architect has had some training, that he has studied under one or more good masters, that he has learned about different materials and made up his mind as to their respective use. Let us also consider that he has traveled in Europe and the old world, there to view the beautiful examples of the past, and that this has enabled him to discriminate between materials and their use, their respective function and their decorative effects, and finally let us take for granted that he can realize the value of colored or plain terra cotta in architecture. We will agree that if one has had such an educational opportunity he certainly would be justified in decorating himself with the title of "architect." Well, he may be so according to the general meaning attached to the word, but it does not necessarily ensue that his ability as a draftsman has provided him with imagination. Right there is the very difficulty which confronts architects as designers and you as producers. We all know that though a man may call himself an architect he may not be the kind of an architect the name implies and with whom you expect to work. As one of you said, there are "architects" and "ar-tchi-tects," but the latter will disappear in time.

And again, consider the present generation of architects. When architectural training was offered in schools or universities, about thirty or forty years ago, most architects were for the greatest part, untrained and architecturally uneducated. They were almost without exception draftsmen who had graduated themselves in architecture. Now we find that the younger generation who comes out of the architectural schools is better educated, better prepared and better trained than the older. Just remember the fact that the number of schools has jumped from ten, perhaps twenty years ago, to forty-four at the present day. This means that there are centers of architectural education and training practically everywhere in the country, and that the young man who wants to enter the architectural profession has an opportunity of obtaining the right kind of education regardless of where he lives. It does not matter that his home be in Arizona or Southern Texas or New Mexico, or you might say even at the other end of this new world, he can today find a center of architectural training not far from his home and thus is not obliged to cross the continent to go east as was the rule a quarter of a century ago.

Ten years from now you probably will find that there will be more new centers and more new schools founded, every one of them with great ambitions. If, each year, you could attend the meeting of the Association of Schools of Architecture, you would see that those schools which are not members of the Association but nevertheless send representatives to the meetings do it for one reason only, namely, the benefit derived from the constant exchange of opinions among schools, rather than for the honor of belonging to the Association. That interest in the right development of architectural education has done more for the improvement of our schools and the courses offered by them than anything else I know of. You will find today in our schools young men who have a clearer understanding of our profession and of the opportunities it offers than was the rule ever before.

I referred to the daring of architects in my address. That daring can not exist unless it be prompted by *imagination.* If the architect has no imagination you, material men may for months and perhaps years, talk to him of the possibilities of colored terra cotta in architecture without result. He will be entirely deaf or will not listen, and if he listens he will not heed.

However, the time will come soon, let us hope, when the terra cotta manufacturer will find no difficulty in giving the architect what he wants, because he will find him more receptive and better aware of the proper use of terra cotta and of its wonderful possibilities. The day will come when the architect will call on the manufacturer as on a friendly collaborator with whom he will try to find out the best solution of his problem. He will come to his office as he does in regard to the specialized engineer and will say, "Tell me how far I can go in this application of your material. What is your opinion?"

The terra cotta man will be the expert. Just now the architect is not in the mood to listen because he thinks not of the possibilities of terra cotta when used as such. On the contrary he thinks only of terra cotta as a substitute for stone, granite, marble or any other material. This, in my mind, is entirely wrong. Terra cotta, excepting brick and hollow tile, should be used exclusively as a decorative and not as a structural element. One of its various applications I particularly wish to present to you. It is that which is found in some countries and large cities of Europe. You will find in Paris, Munich, Frankfort, Vienna, and elsewhere whole façades of buildings decorated with a special kind of terra cotta, called in France "Gres Cerame," and by some other name in other countries. This is nothing but ceramics applied to building decoration. Such use is not that of a structural element, but only that of a decorative one, mostly applied in squares, easier to handle, and also in other convenient forms not suggesting the use of stone in a structural way. This is precisely what I would like to see here. I do not object to an applied front, if it is beautiful and treated in a manner that will make it recognizable at once, as in the Certosa in Pavia. But, whenever I see an imitation of stone or granite in terra cotta I frankly say I am not in sympathy with it. It is exactly what I meant to say a while ago.

MR. GATES:—Do you mean if any *surface color* which is not plain resembles the granite or brick or the block, that it resembles the *piece* of granite?

PROF. FERRAND:—No, I mean if it gives the impression of an imitation of granite.

MR. GATES:—My point is this, is it a pure, fast texture or surface block?

PROF. FERRAND:—It may be both and therefore have a tendency to create an impression that should be avoided.

I know you are now in the transitory period. Terra cotta use in this country has only started and its future, although no one can prophesy to what extent, is undoubtedly very great, because it is a material easy to apply on a surface and entirely fireproof. When glazed it will last forever and its lasting qualities will recommend it to the architect. It has a splendid future and I think the period of imitation is only a transitory one, and also that before long the architect will be so educated as to understand that it is truer to have beautiful decorations in terra cotta expressing terra cotta and not something else, than to try to imitate with terra cotta, a stone building.

It will not materially affect you. You will manufacture just as much as you now do and probably a great deal more, but you will do it according to the real principles of art and architecture. That is my belief. I am well aware of what we both have to contend with. I may perhaps, come tomorrow to some of you and say that I want a course of granite (in terra cotta) for my building. If I do so it will be because I am absolutely forced to do it, but if I can have my own way I will not resort to such a substitution and will utterly discourage it. I shall try to educate my clients.

To educate the client is the most difficult task of the architect. You referred to that fact a minute ago when you said you had a client who was very difficult to please. The architect has such clients all the time. An architect recently had to build a house for a man and his wife who was associated with her husband in business. As long as he dealt with the husband, he encountered little difficulty, but when the lady made suggestions he did not know what to do. Finally he had to stop until he made her realize the vital difference between her work and his and that she must recognize his architectural qualifications and not interfere with the work.

May I give you one other example, a personal one? Not long ago one of my university confrères, a member of another department of the university faculty, came to see me about a house he wanted to build. He inquired about the architect's fee on small houses. You know that the architect gets practically no fee at all when he gets 6% on a structure costing only a few thousand dollars, as the cost of drawings and other expenses consume it all. He can not afford to deal with very small problems in an unprofitable way. My friend did not seem to be pleased with the fee mentioned so he notified me several weeks later that he had discovered a carpenter who knew how to read blue prints and was going to design and erect the building. There is little hope with clients of this type.

MR. SHEFFIELD:—I think our trouble arises from the point of view. The material must have some color. If we make it white, they say it is calcimine texture; we can not use all colors of the rainbow, but must have some color. Instead of matching granite we have given our samples a mottled effect that was never seen in granite and could not be had in granite. We did this in order to get away from this so-called "bath room architecture." We have found since, that architects have responded. We have been asked very seldom to imitate granite; instead, the architect will ask for a mottled combination that will harmonize with my building. The samples that we had were made for that very purpose, and we deplore very much that the architect himself named the material "granite terra cotta," as we never used the term. We speak of mottled surface.

PROF. FERRAND:—That is much better. I dislike to give any name to it and above all to call it by a name not intended for it.

MR. SHEFFIELD:—It is not so much a matter of color, or the shape of the block as it is the imagination of the architect. If he would design clay and think of it as clay, it would not make much difference about the color or shape or size of the block.

PROF. FERRAND:—You full well know you can not use clay as you use any other material. It is something entirely different, physically, chemically, structurally. It possesses a plasticity which none of the other materials have. It can be colored at will whereas this is undesirable with granite, stone or marble, which do not lend themselves to it. You have to back clay, and you do not have to back stone. A stone may be taken out of the quarry and be put into the building. It is a structural element, while clay calls for some backing and you can therefore see how it may interfere with the design. Moreover, there is the shrinkage. Of course, you may account for it, but in certain cases it is difficult and materially impossible to obtain two pieces that will match absolutely. There are always some discrepancies in line, either horizontally or vertically. You can not entirely remedy that and the wise architect knows he must not expect with terra cotta that horizontal or vertical line absolutely perfect, which he can get in stone or marble. For instance, you well know that a terra cotta column must either be fluted in order to conceal the joints, or else look like the assembled pieces of a mould rather than the column itself.

It is, therefore, up to the architect to find such uses for terra cotta as will justify these irregularities. It has been done in the past and will again be done in the future. Why should we, therefore, try to make terra cotta play the part of granite, stone or marble? It can not be substituted for any of them because the effect produced will never be identically the same. Let terra cotta be frankly and honestly terra cotta, and granite, stone or marble what they are.

MR. SHEFFIELD:—That is exactly what we think.

PROF. FERRAND:—You can get beautiful effects in plainly colored or in glazed brick. There is no question about it, but you can do that also with square tiles which I like better because they are frankly applied material and not structural material. They suggest a decorative and not a structural element on the wall.

The only terra cotta we really use in our walls as structural elements are bricks and hollow tiles. All the others put on the outside are nothing but tiles of a special shape, if you wish, but tiles attached to the wall. They constitute a veneer and veneer let it be, provided it will not deceitfully imitate another material.

You are obviously not to blame for that imitation. As an architect, I will say the architect is to be blamed. But you can and always should tell him that you can just as well make a square panel as one that suggests some different material. In fact, it will be far superior, because it will be more expressive of its nature and function. In a word, it will be more truthful. That is how you can coöperate with the architect.

I do not mean to say that you have been in the wrong in trying various effects in terra cotta. You are absolutely right and I am satisfied you are only started. Your enterprise is still young and many more effects will be discovered in the future. Is it not wrong though, to continue the use of certain kinds of terra cotta to deceive and make people believe that stone or some other material has been used instead? That is the whole question. I would always rather have a terra cotta front purely expressive of terra cotta than a front which would remind me of stone, because it would be false stone.

MR. SHEFFIELD:—Stone was used, at first, because it was the best material at hand, but if the architect has a better material now with which to express himself, why use stone, because it is the only material used a long time ago.

Stone, a long time ago, was the first material man made an ax of; man made steel, therefore steel was an imitation for that purpose, at one time.

Now it is not. It is mind working on the best material at hand, to express yourself, that makes it the right material, and because stone was cut in a certain height necessary in the construction of buildings is no reason why other material can not be used in the same way without calling them imitations of stone.

Because the artist in ages past used a certain profile on a piece of granite, if I use it on a piece of terra cotta, I am imitating granite. That is the point upon which we can not agree with Prof. Ferrand.

CHAIRMAN RHEAD:—I always find that when three or four classes of people get together, for instance a practical man, a business man, a technical man, and an artist, they each have their own language, and their own ways of expressing themselves, yet, each may mean the same thing. They simply express it in a different way. I think most of you who have talked with Prof. Ferrand have the same idea that he has. I think the whole thing should be debated from a purely decorative point of view, and I think what Prof. Ferrand means to say, and what other architects have already said is that there are possibilities in terra cotta that have not been developed.

Being a member of the Architectural League I know the architects and I know they are intensely interested in the possibilities of terra cotta work. I know, too, that there are men who are willing to go a long way to be able to demonstrate their possibilites.

At the last Architectural League Exposition, a number of architects had designed rooms, buildings and models showing exteriors and interiors, illustrating the possibilities of architectural polychrome treatment. I think that if you were represented at the League each year with some exhibit of that kind, it would be an enormous influence for terra cotta work.

MR. SHEFFIELD:—They have been represented. The Eastern Company spent a great deal of money on it.

MR. HILL:—I do not know when it was, but about three years ago, some of the companies had displays.

MR. GATES:—I think the main possibility of terra cotta is in the use of color in a building, both for interior and outside decorating, using this idea in every room suitable for it, especially kitchens and bath rooms.

THE ORGANIZATION OF A DECORATIVE CERAMIC RESEARCH DEPARTMENT[1]

By Frederick H. Rhead

ABSTRACT

Artistic development has been slow in the clay industries and has not yet arrived at that stage where it can be legitimately considered a functioning organization activity.

A research organization is a business activity and not a purely scientific venture. Therefore, it is incomplete if it concentrates on any one essential branch of the industry to the exclusion of the others. Future business possibilities are obviously the main activities.

A budget should be arranged to cover a definite period and a program to provide for a definite result since research work involves considerable expenditure in labor and equipment.

The typical art pottery organization is described, giving the qualifications of the various plant executives and directing heads. The research program in relation to losses is discussed. The types of losses are classified. The investment required in connection with a typical organization of a stated size is outlined. The development program with the results for the first twelve months and the year's results against the expenditures are summarized. The position occupied by the clay working industries in comparison to other national industries is discussed.

Introduction

The past general attitude of manufacturers towards research in connection with decorated ceramic products has been rather nebulous in character. In the decorative field of ceramic work where the draftsman, designer, decorator, architect, sculptor, modeler, craftsman and practical potter play an important part, there has been no organized effort to investigate commercial possibilities and improve manufacturing conditions.

A few individual manufacturers have realized the necessity of giving some attention to this branch of their business, but for many obvious reasons, artistic development has been very slow in the clay industries, and it certainly has not yet arrived at the stage where it can be legitimately considered as an organized functioning activity.

In the one or two instances where concerns are making serious attempts to develop the possibilities in the commercial fields under discussion, many unfavorable factors which would not be present if the activity was operating on strictly business principles, are constantly retarding rational progress.

Everyone intimately concerned with the production of any class of ceramic product requiring the services of decorative and allied skilled specialists has encountered difficulties of a practical or artistic nature which at best have been so costly and troublesome that nine out of ten attempts to produce have proved unsuccessful from a financial point of view. This has even been so in many cases where the result from an artistic or practical point of view was all that could be desired.

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[1] Delivered before the American Chemical Exposition, N. Y. City, Sept. 15, 1922.

The remaining so-called successful activities have survived either because the organization in question possessed a purse long enough to stand the strain, or because of the exceptional executive and practical skill of the individual guiding the activity, and more often because of a combination of these two conditions.

From whatever angle this subject is discussed (and there are many viewpoints) the whole matter filters through to the final and immutable question of dollars and cents, or profit and loss. In the commercial field the activity must yield a profit or it can not continue to exist. The concern in question may have the most desirable assistance and be producing the most creditable ware and yet not be a solid business activity, because the income is not at least equal to the expenditure. Further, an activity which may be earning profit at the present time may not be doing this five years from now.

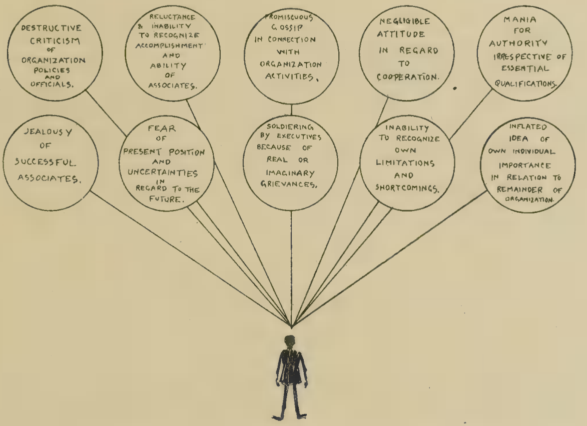
DESTRUCTIVE CRITICISM OF ORGANIZATION POLICIES AND OFFICIALS.
RELUCTANCE & INABILITY TO RECOGNIZE ACCOMPLISHMENT AND ABILITY OF ASSOCIATES.
PROMISCUOUS GOSSIP IN CONNECTION WITH ORGANIZATION ACTIVITIES.
NEGLIGIBLE ATTITUDE IN REGARD TO COOPERATION.
MANIA FOR AUTHORITY IRRESPECTIVE OF ESSENTIAL QUALIFICATIONS.
JEALOUSY OF SUCCESSFUL ASSOCIATES.
FEAR OF PRESENT POSITION AND UNCERTAINTIES IN REGARD TO THE FUTURE.
SOLDIERING BY EXECUTIVES BECAUSE OF REAL OR IMAGINARY GRIEVANCES.
INABILITY TO RECOGNIZE OWN LIMITATIONS AND SHORTCOMINGS.
INFLATED IDEA OF OWN INDIVIDUAL IMPORTANCE IN RELATION TO REMAINDER OF ORGANIZATION.

FIG. 1.—Unfavorable mental attitude of plant executive.

In order to have a staple business, the manufacturer must be in a position where he is realizing a fair proportion of the possibilities in his particular line. There are many manufacturers today who are making what they consider a satisfactory profit, but who are not realizing over 10% of the potential market possibilities. This is not a secure business condition. For instance, a certain concern engaged in the manufacture of art specialties has an output of approximately $300,000 a year. But, assuming that these specialties represent less than 20% of the potential market, and that there are at least three domestic and from fifteen to twenty foreign competitors concentrating on the obvious possibilities while a far greater field of potential possibilities in similar lines are untouched, it is easy to see that the manufacturer must give serious attention to the study and development of all allied types. He must do this in order to be in a position to improve the present product and to extend the line in every direction compatible with materials and conditions at hand. The market for art wares is as illusive as the moving picture or musical comedy market, and infinitely more difficult to gauge, because no serious attempt has been made to properly classify it, or even crudely approximate its value.

It is not the purpose of this paper to attempt to analyze this or any of the various ceramic markets. It is enough to state that the present domestic source of supply is the result of the natural growth of the pioneer activities of forty years ago or thereabouts. With few exceptions, processes and methods of manufacture are unchanged. There is no organization in the advanced sense of the term. Not one plant in a dozen has an adequate cost system, and "research" is confined to such activities as the occasional purchase of some domestic or imported "best seller" in order either to copy it outright, or to make something closely approximating it in general appearance.

In other words, the manufacturer is satisfied to meet the present demand without thinking of or considering the far greater potential market, and planning (as an efficient executive in any other business would do) to create a demand for this market. Of course, under present conditions, it would do him little good if he succeeded in creating a demand, because the great majority of organizations as they exist are entirely incapable of supplying such a market.

The Value of a Research Department

This condition refers us back to the question of organization and the need for an efficiently functioning research department. To attempt to lay down definite laws in regard to the planning of a research department and its relationship to the remainder of the organization would be folly, because the problems involved vary with each concern and according to the personnel of the organization.

It is obvious that there should be a director or some individual responsible for such an activity, but in two or three cases known to the writer, the owner of the concern is personally interested in dabbling in experimental work. In other concerns, the decorative work is in charge of specialists who are clever individual craftsmen, but who have no executive ability, and who are entirely unable to direct anything larger than a one-room activity. Many of these men will not teach others the fundamentals of the practical work, fearing that such an attitude would be harmful to themselves. A third condition relates to the type of organization. In some places, the development work is in the hands of the ceramic engineer, who in the large majority of cases possesses about as much executive and business ability as a peanut vender.

Unless the concern interested in progressive development is large, and the officials responsible for the factory policy are solidly back of such an undertaking as an up-to-date research department, the three conditions mentioned will be found inimical to any addition to the present old fashioned and imperfectly coördinated type of organization.

But as such an addition as a research department is already recognized as one of the most vital essentials in connection with modern plant organization, no amount of selfish or ignorant individual opposition can succeed in obstructing the organizing and efficient functioning of such a department, especially if it is in the hands of a man who understands artistic, practical and technical standards, world markets, sources of supply and who has the ability to direct factory operations.

Plans for the Research Department

In outlining a decorative research department, the writer must base this upon some particular type of existing organization, or he must assume that the undertaking is entirely a new one. In the latter case, it is a comparatively simple matter to submit a program, because the research activity would naturally take its place in the initial organization. But in the former, the activity would have to be planned in such a manner that it would commence as an independent department and then gradually be absorbed and tied into the factory organization without interfering with the present shop practice or existing personnel.

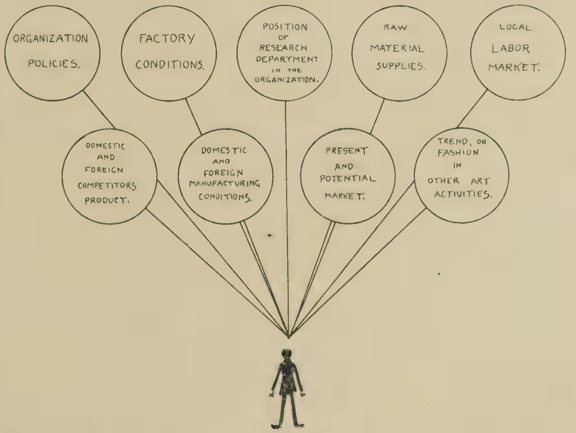
ORGANIZATION POLICIES.
FACTORY CONDITIONS.
POSITION OF RESEARCH DEPARTMENT IN THE ORGANIZATION.
RAW MATERIAL SUPPLIES.
LOCAL LABOR MARKET.
DOMESTIC AND FOREIGN COMPETITORS PRODUCT.
DOMESTIC AND FOREIGN MANUFACTURING CONDITIONS.
PRESENT AND POTENTIAL MARKET.
TREND, OR FASHION IN OTHER ART ACTIVITIES.

FIG. 2.—The Research Director must be familiar with the above activities and conditions.

For the purpose of this discussion, we will assume that the officials of an art ware plant doing the business of the size previously mentioned have decided to adopt a policy covering greater development facilities, and to include in the present organization a properly equipped research department. A survey of the conditions within this organization will approximately result in the following facts:

1. **Size of Business and General Operating Expense:**

Paid in capital	$100,000	
Output approximately	300,000	
Material	60,000	
Direct labor	80,000	
Manufacturing expense	100,000	
Selling and administrative expense	24,000	
Total income		$300,000
Total expenditures		264,000
Net profit		36,000

2. **Ownership.**—Family corporation.

3. **Management.**—The president and general manager is the founder of the business which is over thirty years old. He was formerly an insurance man. Possesses good general business knowledge. Is a capable executive and interested in possibilities of development, a good judge of standards, and well acquainted with the local conditions. Not so well acquainted with the artistic and technical side of the work, but capable of judging results. He is rather skeptical in regard to technical and artistic executives, because he has experienced a number of rather costly experiments in connection with this class of help.

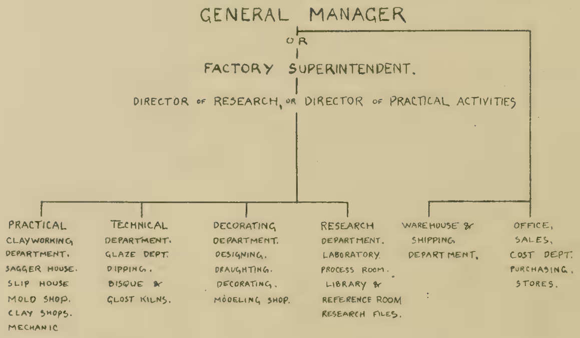

FIG. 3.—Chart showing type of organization that has proved successful.

4. **Organization, General Manager.**—The general manager practically directs the entire factory operations, and about all the routine details are brought to his attention. He spends little time in the plant, and the heads of the various departments consult him individually in connection

with their own particular activity. There is practically no coördination (as understood in modern plant practice). Each department head looks after the interests of his own department fairly efficiently, but has little or no interest in production outside his own department. The various heads have no official title, and there are no group conferences or consultations in connection with factory activities.

(*a*) **Factory Engineer.**—A good construction man. In charge of power, heating, lighting, machinery, plumbing, repairs, carpenter shop, etc. Unusual repairs or new construction is referred to the general manager. Otherwise, the engineer acts on the request of the various department heads. He is pretty much of a czar in his own department, and the other officials are likely to experience delays in getting essential work done if they should be "in bad" or happen to "cross" him in any way.

(*b*) **Head, Clay Shop.**—A fair practical potter, according to local standards which are not high; no technical education; will force production at the expense of good potting with the result that the loss in the clay shop is much higher than it should be. Will act only in regard to better quality when complaints come in from customers. Is not susceptible to new ideas and changes in method. Is not particularly friendly to the other officials and resents suggestions or comments from them in connection with standards.

(*c*) **Kiln Boss.**—In charge of a former kiln placer who has been broken in by a former kiln fireman. Very reliable and willing. Not an experienced fireman. Fires to cones and draw tiles. There is no pyrometer equipment. So far as can be ascertained, no actual records are kept. Glost kiln losses average approximately 30%, but this is not consistent. Some kilns will show from 80% to 90% acceptable production, while others will be 50% or even less. Four or five different types of glazes requiring different kiln treatments are in general use, and the kiln position for each glaze is constantly changed. No standard practice or scientific method of control as understood today. There are no firing charts for references or record purposes. The sagger losses are particularly heavy. Fifty per cent do not survive the third or fourth firing in the glost kiln.

(*d*) **Head, Glaze Department.**—This man is a graduate of one of the best technical schools. No previous practical experience. Possesses the qualifications of a capable and efficient ceramic engineer. About all of the technical problems are turned over to him. He gives some attention to body and glaze control and generally arranges the kiln positions for the various products, but he has no defined authority either in the clay shop or the kiln shed. He is not a practical potter in any sense, and has no understanding or appreciation of art or decoration. While he is capable of formulating glazes which are technically good, because of his lack of art training or feeling, he is entirely incapable of judging color values or textures. In other words, he will develop glazes which may have technical interest, but which have no artistic value to the trade, while he will reject colors and textures which would be highly acceptable. Although he has had no practical experience in plant operation, he is more interested in the executive work, as he understands it, than in the technical work he was trained for. Because of this failing, he is constantly interfering with the other activities and assuming authority which he does not possess. He has absorbed the modern technical school philosophy which instills in the mind of the technical student that he is the only highly trained specialist in the ceramic industry, and which also suggests that this class of training especially fits him to boss the job. He has somewhat of a contempt for the practical potter, because the great majority of the practical men have had no technical school training, and because they can not discuss factory problems in technical language. It is his conviction that all artists and decorators are cranks, and at best, a high grade of skilled labor.

(*e*) **Head, Decorating Department.**—A former decorator who has had a few drawing and painting lessons under a local art teacher. One of the many unfortunates who are born "with a talent for art" and who are drawn to any local industry using the services of a decorator or draftsman. He is able to apply elementary decorative forms in a workmanlike manner, and knows two or three decorative processes. He uses mechanical devices to cover his inability to draw easily and quickly. He has absolutely no art training as judged by European art school standards, and consequently possesses no knowledge of historical ornament ceramic shape construction, or the technique of the painter, etcher, sculptor, or craftsman. His stock-in-trade is his practical experience in the two or three simple decorative processes in current practice. He is not in any sense a designer or originator. His idea of a "new line" is an adaptation of a popular line of some competitor, or in extreme cases, a gross plagiarization of some historical type. There is no attempt to study the market or to try to raise the standard of commercial art work by working out new developments. When it is necessary to get out a new line, he is so saturated with the knowledge of a successful competing product that he can neither analyze the cause for its success nor produce a type that is not based upon this particular "best seller." Consequently while the resulting product from a practical and technical point of view compares favorably with competitive wares, and while it is commercially acceptable to a certain class of department store trade, its market is limited by its own artistic shortcomings. He does not realize that there is a large purchasing public who will not buy pottery that is obviously badly designed and unskillfully executed. The high schools, universities, fashion magazines like *Vogue, Vanity Fair,* and the *House Beautiful,* and even the moving picture industry have ingrained into the younger generation a conception of art standards, that while limited in scope, is high enough to be able to recognize acceptable conventions to the rejection of what is considered as either old-fashioned or in bad taste. In short, our decorator under discussion and, unfortunately, the average ceramic decorator is not educated up to the standard of the average high school student or prospective pottery purchaser.

(*f*) **Head, Shipping Department.**—A most efficient and hustling executive. While most of the product is sold from stock, he is very careful not to over or under stock. When special orders are being made, he will keep in touch with various departments and assist in routing the product through to the shipping room. He is a good judge of standards and is very quick to report any tendency such as shop carelessness or deviation from a fixed standard. He is the one executive who is on friendly terms with all the other heads of departments, and in an unofficial way does more in the way of general supervision than any other person in the plant.

(*g*) **Office Manager.**—This man grew up with the business and has acquired all the faults and few of the qualities of the "old and faithful servant." As one of the oldest employees, he expects all the reverence and respect due to an antique, but unfortunately his "patina" is the result of disuse and age. He gives scrupulous attention to those matters which come to the attention of the general manager, who accordingly is favorably inclined toward him. He is naturally careless in his correspondence and treats all dealers as his natural enemies. He is a difficult proposition when handling claims and complaints. The dealer is always in the wrong and the factory always right. His attitude toward the salesmen is distinctly unfriendly, and his lack of coöperation often causes serious dissatisfaction among customers. He can not understand why standard lines of ten or fifteen years ago are not still popular, but believes it is because the buyers are distracted by too many new products.

Summary of Organization.—It will be seen from the given description of the organization that the general manager is also factory superintendent and director of department activities. In addition to his legitimate duties in connection with financing the undertaking and handling the business and sales, he is not only burdened with the multitudinous practical details that come up daily, but because there is no other directing factory head, he is the active force in each individual department. Under such circumstances, results are limited not only by lack of organization, but by the limitations of each individual in charge of a department. If the general manager personally can not supply an essential quality lacking in one of his executives, the results fail accordingly. There is no question that this particular organization (if it can be called such) is seriously lacking in a number of important essentials, and that the manager is handicapped to such an extent, that it would be a mental and physical impossibility to manufacture products with anything like a possible efficiency demanded in almost any other industry.

Development of Commercial Art Pottery

General History.—When the plant was organized over thirty years ago, the product consisted of a single line of crudely and atrociously designed flower pots glazed after the manner of the so-called English "majolica" ware.

This was the standard commercial art pottery for a number of years. About 1880 a well-known pioneer art pottery produced a line of slip-painted vases after the style of the French Barbotine process, but painted and glazed in rich yellows and brown tones. A demand was created for such a ware so that the originators were entirely unequipped to supply or perhaps they did not realize the commercial possibility.

However, the concern under discussion did see this possibility, and then proceeded to manufacture a similar product. The venture was so successful that other art potters followed suit, and the process and decorations were widely and vilely copied. The original concern making this ware then produced vases and other wares based on the type made by Royal Copenhagen and similar concerns. The decorations were still naturalistic, but were painted on light grounds in pastel-like colors, while white glazes were used instead of the rich iron yellow glaze. The various commercial art potters again followed suit, and tons of this product were put on the market.

About this time, mat or vellum glazes began to be used, and while the pioneer art pottery mentioned was dabbling in this type of glaze, the commercial potters immediately grabbed this possibility, and if the resulting product had at all been acceptable to a cultivated taste, they would have flooded the earth with it. As it was, millions of pieces were put on the market and sold.

The Paris Exposition of 1900 was the happy hunting ground for ceramic manufacturers looking for "inspiration." Most of the big European pottery manufacturers and scores of individual studio potters exhibited, and on no occasion before or since has there been on display such a comprehensive variety of decorative processes and ceramic ware.

This period might be classed as the beginning of the commercial art and craft movement. The American potters were not slow in responding to the impetus given to commercial art pottery possibilities, and while at that time they did not possess the skilled help necessary for the production of such types, many foreign craftsmen came to this country to connect with the American concerns.

Unfortunately, the American manufacturers did not understand the European conditions, and because of this, they quickly engaged any foreigner who applied for a job and gave him privileges out of all proportion to those he would enjoy at home, where he was subject to strict supervision by a capable director and not allowed to experiment or dabble without a defined program. Although there were good results here and there, a condition developed where these foreign specialists (merely bench decorators in their own country) fearing that their "secret processes" would be taken from them, insisted on working behind closed doors. At the best, they refused to teach others the various processes, and to enter their formulas and processes as part of the factory records. This attitude resulted in one-man activities, obviously limiting the production and commercial possibility in connection with their particular process. In some factories there would be ten or a dozen such specialists working independently and fiercely antagonistic toward each other.

A few of the manufacturers objecting to the constant distraction, the limited output and consequent high overhead, simply appropriated what they could of these processes and attempted to make a factory activity of the product. But as most of the foreigners were men who were not particularly expert decorators in their own country, no important development followed, although this foreign element did exert influence at a time when domestic ceramic decorators were an unknown quantity. But while there were scores of different "lines," and an endless series of varied decorations, the actual processes, factory methods and standards remained practically unchanged, with the exception of two or three art potteries whose output was so small as not to be properly classed as commercial products.

The Market Today

The bulk of American art pottery is beneath acceptable artistic standards. It is not found in company with good books, prints, furniture and rugs or in the possession of individuals who buy Wedgwood, Worcester, Copenhagen, Doulton, Minton, Rookwood, Lennox, Rozenberg, Dresden, Limoges, Copeland, Rorstrand and the best of the European and Asiatic craft potters.

Its market ranges anywhere from the premium-giving tea and coffee dealers to the middle-class trade of the department stores, and represents, roughly speaking, about 30% of the art pottery buying public, and from 10% to 15% of the actual value of such products sold.

Consequently, if this estimate is at all approximate, there is an untouched market of 70% of the present buying public, and a value of from 85% to 90% over the present output. And this does not refer to the potential market that is being created by the constantly increasing standards of living, and the rapidly growing interest in art activities.

Present Production.—The line consists of vases and art specialties and is broadly divided into two groups: vases, bric-a-brac and various ornamental specialties, table ornaments, candle sticks, match safes, flower bowls, etc., and the large jardinières, pedestals and umbrella stands. A classification of the various types is about as follows:

Old colored glaze line	5%
Slip decorated, Rookwood type	7%
Slip decorated wares, Copenhagen type	20%
Plain mat glazed product	25%
Modeled specialties	25%
Monochromes or plain colored enamels	15%
Individual decorated wares	3%

About 65% of this product is made in a buff body, and the remainder in a cream colored earthenware. The bisque is fired to about cone 3 and glazed to about cone 01–1.

Research Program

In considering the extent of a practical research department it is obvious that this must be planned in harmony with the present financial and practical resources, and in the first period without a noticeable increase in the overhead. But as an efficiently functioning research department is not a one-man activity, but an organization proposition, the mere engaging of a capable research man does not provide the solution to the problem. It will be remembered that the concern under discussion is doing a business of $300,000 a year and showing a profit of about $36,000. On the other hand, the losses are averaging 30% of the output, which would figure at something over $125,000 sales value. If by increased efficiency, these losses are reduced to within 15% during the first year, this would increase the revenues $62,500. These savings refer only to kiln losses and not losses due to waste and general factory inefficiencies.[1]

[1] With 30% loss, $300,000 equals 70% of the total production which with no loss (an impossible accomplishment) would bring the income up to about $425,000.

Any efficiency engineer who has visited the average art pottery can quickly prove that the plant operations are at best not more than 60% efficient, and the concern under discussion is probably less than 50% efficient rather than higher.

If this standard of efficiency were raised 10% a year for five years (an ordinary accomplishment) the research activity would easily have paid for itself, while the kiln losses would be reduced and production increased without an appreciable difference in the general expenses.

Such results could only be brought about when the research director is given authority to make necessary adjustments, but the general manager has acquired the habit of handling the factory routine, and it is not easy for him to relinquish this. Furthermore, the factory officials have been brought up to the present method of transacting business, and the manager is afraid that they would actively resent the authority of an outsider, a not ungrounded fear.

But if it were possible to do this, the investment connected with the undertaking would consist of the salary of the director plus office furniture, filing cabinets, book-cases, experimental studios, room for filing research specimens, and what special apparatus might be needed. The director would submit his program based upon the obvious present needs and would proceed to coördinate and organize with a minimum of interference and interruption with factory production.

This would be the procedure adopted in almost any other industry. But as stated, modern business practice is yet the exception in the ceramic industry, and it is a question if a manufacturer could be found who would be far-sighted enough to do the rational thing, and, curiously enough to the business mind, the obvious thing. Consequently, the director must bore from without, and proceed by building an organization which will gradually be absorbed by the various departments. This latter method is a more expensive operation, and it takes longer to get results, but this fact should be admitted and should not be charged against the research department, (although it will be). However, conditions are such that the director of research is to commence activities by the latter method.

Before we formulate the program, and outline the results to be attained within a definite period, we must consider the maximum cost involved. The director can not act without spending the firm's money, and he can not act intelligently unless he knows the extent of his budget and its application. He also must be in a position to show the general manager at any time just what is accomplished, and at what cost.

Too many specialists have a negative interest in the organization as a whole. They are wrapped up in their particular activity to the exclusion of allied or connected branches. They also assume the rôle of employee with its too often accompanying feeling of uncertainty in regard to the future. Very definitely they do not regard themselves as organization men and as much a part of the concern as the kilns are a part of the building. They order material and equipment, and plan without full consideration of the money involved, or the expected result from a purely financial point of view. It is contended here, that the successful research man must know what his expenditures are, and that he must check these with ensuing results on a financial basis, and not on a purely intangible basis of assumed accomplishment.

With these ideas in mind, we will assume that a man of exceptional ability is in charge, and that he is to be paid ten thousand dollars a year. It is understood that he is sent to important technical, artistic and business conventions, involving an annual expense of about one thousand dollars. Assuming that the necessary fixtures, furnishings and special equipment cost five thousand dollars (a maximum amount for the first year) and with factory expense in connection with material, labor and operating expenses totaling another five thousand dollars, we find that the concern must provide for an expenditure of something like twenty-one thousand dollars for the first year, or approximately seventeen hundred and fifty dollars a month. What results can be expected from a *practical* and *financial* point of view within the first year to justify a continuance and further development of such a department?

Regardless of the program in connection with new developments, there are, in every ceramic plant, many bad conditions which are not corrected simply because there is no one concentrating on these conditions. The average organization is so used to shop and kiln losses that these are accepted as inevitable, and only to be noticed in exceptional instances or when there is constant complaint from customers.

A 20% loss causes no particular concern, and a product bearing a 50% loss or more is considered as a difficult technical or practical proposition, which is solved by putting the product in a "special" class at a price high enough to cover the increased loss. The average man in charge of operations is a specialist of the most limited type, and he will, more often than not, hesitate to admit his ignorance or limitations in connection with the shop trouble, which will often continue for years when a few words from a competent source might immediately adjust this difficulty and save the concern a considerable sum of money.

Art Pottery Losses

In an art pottery, the art director is, or should be, the best judge of standards, and if he is a practical potter, which should be one of his chief qualifications, he is the man to be responsible for the correction of all faults affecting the quality and standard of the product. Many of these faults may not be obvious to the person who is not trained in art matters and consequently not noticeable to the various officials or even to the trade. But they are noticeable to the trained eye, and because they do affect the quality of the product, steps should be taken to improve the standard of workmanship so far as the acceptable cost of production will allow. Factory losses in art potteries are of three general types:

(*a*) **The Use of Unreliable Body and Glaze Compositions.**—Lack of standards for raw materials. Of imperfectly standardized bodies and glazes. Glazes that are too sensitive for present kiln conditions. Variations in material grinding.

(*b*) **Inefficient Shop Practices.**—Lack of system. Poor drying facilities. Poorly organized mold shop. Faulty mold construction. Poorly designed shapes from a practical point of view. Inadequate supervision in the slip house, sagger house, clay shop, and studios. Dirty and poorly arranged work rooms.

(*c*) **Incompetent and Careless Workmanship.**—Inadequate supervision in connection with the various processes.

It is an unquestioned fact that the mere presence of an interested, capable authority on standards in a clay working plant would result in the material reduction of losses with an effort and expenditure of time which would not seriously interfere with his work in connection with new developments. Acting in the capacity of a coach, he would quickly correct faults which were almost inevitable without such direction, and which would save the concern two or three times the salary in his first year in regard to actual losses. This would result in increased production of a higher standard. A 10% increase in shop efficiency would net the concern $30,000, while a decrease in losses would be a saving in proportion. Some opinions may say that these two conditions can not be taken separately, but it is certainly definite that a mere reduction of the kiln loss will not make the acceptable product higher in quality or artistic value, nor will it mean that many shop inefficiencies will be eliminated. The present production would be increased, because there would be less kiln loss. But if the present production is only 60% efficient, the kiln losses have no relation to this condition, nor would a decrease in sagger losses affect the quality of production. There are opportunities to reduce both the kiln losses and to increase present production by adjusting or eliminating unfavorable conditions.

Value of Research Head

Whether the research head would be allowed to give practical attention to these matters is probably questionable. There are many deeply rooted prejudices in the ceramic industry, and not the least of these refers to anything that suggests departure from current shop practice. These prejudices are more pronounced in localized ceramic industries. But assuming that the research man had no authority to change unfavorable conditions, and that he was operating an entirely independent activity, the fact that he was actively engaged in the plant would be a noticeable influence among those executives who were at all interested in increased efficiency. His work would be closely watched, and notwithstanding the jealousies and criticisms that are ever present in such organizations, the various specialists would consciously or unconsciously exert themselves to a greater effort.

While such results are intangible and due to the presence of the director rather than to his personal accomplishment, whatever results he is known to have attained will also affect the mental attitude of the men responsible for factory production, even if they are not brought into direct contact with the research department. I know of instances where a research man, although working independently of the remainder of the organization, has changed the entire character of process and style of decoration.

In some cases, the different specialists wanted to show that they could do the same things. In others, they wanted to acquire additional experience. But whatever the reason and however detached his activities so far as official action is concerned, the director is, if he is a productive man, a definite force that can not or will not be ignored.

We shall assume that these ideas are accepted, but we shall not reckon such intangible benefits in connection with the investment involved. We shall include only the actual and independent productive results. In recording these activities, we shall divide the year into twelve monthly periods, itemizing the results with the approximate costs and resulting business. For obvious reasons, we are not describing actual processes or giving detailed information in regard to historical types to be used. These are individual problems and will vary with the particular concern and its present market. Assuming that the activities commenced at the first of the year, the results are recorded as follows:

The work is divided into two groups: (A) Organization Work, (B) Productive Work.

First Month

(A. Organization Work)

1. Installation of equipment: Director's office, files, typewriter, desk, drawing cabinet, book cases, cases for factory museum samples, room for record samples, glaze laboratory, modeling room, decorating room, casting room, camera, microscope, etc.

2. Survey of present factory conditions, description of product, and report on present market.

3. Detailed program of activities for the first three months.

4. Planning and printing the research records, formula cards, decorative process cards, shape number cards, cards for factory numbers, files for stencils, estimate blanks, arrangement of filing system, labor and cost records.

(B. Productive Work)

5. Series of fifty sketch drawings showing types of wares to be produced.

6. Working drawings of twelve shapes selected from above sketch drawings.

7. Preparation of three bodies and twenty glazes to be used in connection with these products.

8. Production of models and molds for above twelve shapes.

9. The casting and jiggering of twelve of each of the above shapes (this can be done by the director personally, or the molds can be turned over to the clay shop foreman, who fills in a research cost card showing amount of time and material consumed), but the pieces must be made according to instructions. These sample wares are made from the original molds. No blocks and cases are made for the original test series.

10. Decoration and glazing of the above shapes.

11. The first series of glaze tests and finished decorative samples go to the kiln.

NOTE:—If this seems an unusual or unreasonably large amount of work to be accomplished in the first month, it might be well to state that these notes are taken from a diary recording actual work accomplished in this space of time. However, it must be understood that not every decorative specialist understands modeling, mold making, or even glaze preparation. In such cases, it is obvious that these activities could be carried out in the factory modeling and clay working shops, and charged to the research activities. But because of the standards and new processes involved, it is highly desirable that the director be a man who is capable of executing all the processes under discussion. The fact that he does this helps to determine the standard to be attained.

SECOND MONTH

(B. Productive Work)

1. Further series of ten or twelve working drawings.

2. One week for American Ceramic Society Annual Meeting with side trip to New York to show designs to dealers, and to investigate present and future market conditions in connection with present program.

3. First decorated pieces out of glaze kiln. Conference with general manager to decide modifications and adjustments. These sample wares are numbered and filed for immediate and future reference.

4. Production of models and molds of second series of working drawings.

5. Further series of about one dozen each of new shapes cast or jiggered from original molds.

6. Decoration and glazing of above shapes.

7. Received first series of glaze tests from kiln. Reviewed and recorded results. Formulated second series making necessary adjustments and modifications. Commenced to standardize a palette of colors in connection with three types of glaze suitable for present needs.

THIRD MONTH

(B. Production Work)

1. A second series of completed decorated and glazed samples from kilns. Selected types considered most suitable for present market. Filed successful rejected samples for future reference while holding selected examples for immediate use.

(A. Organization Work)

2. Conferences with general manager and factory salesmen in connection with selected examples which are compared with present product and competitive lines. Costs and factory conditions discussed.

3. Visit to two or three important customers in connection with above selected lines. Report for the general manager on the result of this trip.

4. Samples are coming from about every glost kiln. Each variety and type appropriately classified, numbered, and entered into the process records.

5. Completion of first series of standardized glazes and bodies. Samples numbered and filed, and glazes entered according to their respective types and temperature range.

6. Completion of series of approximately four hundred sample pieces in plain glazes and decorations.

7. Commenced to produce first decorative lines for market. These lines will include new shapes and decorations appropriate for present market with four or five special shapes to broaden various lines. The types will be about as follows:

(A) Commercial or cheaper grades of plain glazed wares.
(B) Selected or middle grade plain glazed wares.
(C) Commercial decorated wares.
(D) Selected decorated wares.
(E) High class special products.

Résumé of First Three Months' Work

1. Productive results. Developed a series of three types of glazes each in eight colors with three shades of each color.

2. Produced the following series of art ware samples:

Type A	100 pieces
Type B	100 pieces
Type C	75 pieces
Type D	75 pieces
Type E	50 pieces

making total of four hundred samples.

3. Completed series of working drawings of shapes based upon selected samples, and to be used for new lines for factory production.

4. Research results. Filed research reports giving formula and description of process, method of manufacture, type of labor involved, and itemized estimate of direct and indirect labor and material cost in series of 500, 1000, 5000, and 10,000 pieces of each item.

Costs in Connection with Above Activities.—The three months program has cost approximately $5500, $2500 being the director's salary, and $3000 being the proportionate expense for equipment and factory expense for the three months.

Application of These Results to the Research Program.—(1) The three standardized types of glazes are being used in connection with current developments; (2) the new line s of the various types have been selected from the completed samples to date; (3) the working drawings are being released for modeling and for the production of actual sales samples; (4) based upon the research cost and production reports of the particular samples, the sales prices for the various lines are being made. The sales campaign is also being planned.

The General Manager's Summary of What Has Been Accomplished for Expenditure Involved.—1. He has at his disposal a standardized series of new glazes for future production and has adopted a system which will permit of definite glaze control both in regard to color and texture.

2. He has formed the nucleus of a collection of classified research samples for reference purposes in connection with shape, construction and design.

3. He has adopted a system permitting central control in connection with the production of new lines.

4. He has formed the nucleus of a library of research reports for reference purposes in connection with the technical, practical, artistic and cost problems constantly arising in the plant, and the marketing problems in connection with sales policies.

5. Because of the above four activities, he is in a better position to define the factory policies, and to direct and control the activities in both the research department and the plant without being dependent on the idiosyncrasies of art specialists or any one element of specialized labor. In other words, the system outlined will make development work an organization activity instead of placing it in the hands of four or five individuals whose activities are not properly coördinated.

Fourth Month

With the commencement of the production of the actual samples, the research activity should begin to tie up with the factory organization to the extent that the latter provide facilities for the partial or entire execution of the samples, for instance about 65% of the total production is in class

A and C. Attention will be given to these two types first, and arrangements made to have such samples produced by the regular factory help. A research order O.K.'d by the director or general manager accompanies each lot of samples to be made, provides for the recording of labor, material, decorating, firing and other costs allowing for percentage loss. The resulting figures will both assist in making the sales price, and also give the costs to be charged against the research department.

In almost every plant, there are workmen who take care of the special work in their respective departments. Such men can very well be entrusted to assist in making the samples and in paving the way to factory production. But while a director possesses no official authority either in the clay shop or studios or over the special labor involved, he is responsible for the successful production of the samples, and should give instructions both in regard to methods and processes and be in close personal touch with those engaged in this particular work.

With such a program in mind, the director can then concentrate for a period on the production of models and the glazing and decorating of the cast and jiggered samples, leaving the blocking and casing, casting and jiggering, glaze making and firing to the respective factory departments. Assuming that he makes an average of three models per week, and that the present line is to consist of twelve models in each type (A and C) allowing for the time taken in decorating and glazing the various models as they are molded and cast, we find we have a sixty days' modeling program for the two lines.

But as a completed model is immediately sent into the mold shop, it is only a matter of a week to ten days before clay samples would be made, and a further period of from twelve to fifteen days before the sales samples begin to come from the kiln. With the general program planned as suggested, the trade would be already familiar with the type of work being produced, and a condition created where the samples could be presented to the trade and orders taken without a longer period of delay.

In the art ware business there are many standardized articles that find an immediate market, and it is such items that should receive the early attention of the research man. With these facts accepted, we find that it is possible to present sales samples of two different lines to the trade within the fourth month of the activity, or certainly within the fifth month, if it is found advisable to ship directly from stock. But under no circumstances should stock be made of products that have not been shown to the trade, or which have not met with definite approval from more than one prominent dealer. It should be realized that the dealer is just as much a part of the organization as the man who is producing the goods. With such coöperation there is no doubt whatever that a well designed and finished product will enjoy an immediate market.

Activities

1. Completion of fifty pieces of each line (A and C).

2. Wares carefully examined and standards of workmanship are adopted. (Those concerned with the production are informed in regard to acceptable maximum and minimum variation in size, color, and general finish. When the actual production commences, those in charge of each process are shown actual acceptable and non-acceptable examples. Such examples are kept on file for reference purposes to be used when there is a question of variation of standard. No one concerned with the practical work is left in doubt in regard to the various essentials necessary to the production of satisfactory wares).

3. Manufacturing costs, manufacturing expense, sales and administrative expense and wholesale selling prices are determined. (The expected percentage loss is carefully figured and reckoned with in determining the manufacturing cost.) If there is a market for seconds, these can be allowed to accumulate and turned into cash at various periods. Assuming that 90% of a product is satisfactory, this leaves 10% to figure either as a total loss or to be partially recovered when seconds are sold. If half of this 10% is clay, bisque, or glost kiln loss, this leaves 5% of product to be sold at 50% of the regular wholesale value. This means that $20,000 of ware (sales value) with a 10% loss only nets $18,000. But if 5% realized $500 or half the net wholesale price for perfect ware, there would only be a $1500 loss instead of $2000. This $500 would cover the actual loss incurred, because deducting the 12% profit and the 30% sales and administrative expense, the actual cost of producing this $20,000 of ware would be $11,600 and the 10% loss would figure at $840. A 5% recovery on the sale of seconds would be $500, which would be seen to be an actual money loss of $400 in labor and material to be added to cost of production.

4. The line is released for the market.

5. Modeled twelve shapes for line B.

6. Glazed, cast and jiggered fifty samples of each of the above type.

7. Research reports, process records and observations in connection with the production of the samples.

Fifth Month

1. Line B from kiln assembled and recorded as was done when lines A and C came from the kiln. Standards and costs recorded as in activities 2 and 3. (Fourth Month.)

2. Ware released for the market.

3. Preparations for orders for lines A and C. Mold making, casting, decorating, kiln, stock and shipping facilities arranged.

4. Records and research reports as before.

SIXTH MONTH

1. Received and commenced to manufacture first orders on lines A and C. (The production is watched very closely so unexpected and unfavorable developments can be promptly adjusted.

While this is now entirely a factory activity, the research director is working in close coöperation with the factory officials concerned with this production. The various standards in connection with any involved weight, thickness of piece, finish, period of drying, temperature of bisque, thickness of glaze, glost kiln treatment, all of which have already been decided upon, are modified or adjusted to suit the condition of quantity production. Any change is immediately recorded and noted on the process cards.)

2. Modeled the twelve shapes in line D.

3. Cast and jiggered fifty pieces of each shape.

4. Recorded and filed necessary reports in connection with practical operations and the various elements pertaining to production.

SEVENTH MONTH

1. Amount of factory production on first orders $2500.
2. Modification and practical adjustments in connection with the new factory production.
3. Further samples and developments as a result of observations of the results of the new production in comparison with original samples.
4. Four new models in accordance with the above.
5. Filed reports, cost estimates, new process records, etc.
6. Further series of glaze tests for standard colors not in present line.
7. Worked out a labor and production program based on sales and factory production of approximately $50,000 for the remaining five months of the first year period of this research experiment.

EIGHTH MONTH

1. Production: $4000.
2. Same activities as in seventh month.

NINTH MONTH

1. Production: $6500.
2. Ten day trip to Chemical Exposition, New York, and visits to dealers who had received shipments on new products.
3. Reports to the general manager on above trip. The reports covered the following activities: A. Chemical Exposition. B. Dealers' opinion on new lines and their reception by the public. C. Recommendations and suggestions.

4. Adjustments and modifications in connection with the new factory product.
5. Production of research samples modeled last month.
6. Two new models based upon recommendations of dealers in accordance with report C (this section).
7. Filed necessary reports and factory data.

TENTH MONTH

1. Production: $9000.
2. Commenced work on one dozen new models for next year's line.
3. Filed and recorded necessary reports.

ELEVENTH MONTH

1. Production: $12,500.
2. Completed twelve models.
3. Glazed and decorated sales samples of new models.
4. Recorded and filed necessary reports.

TWELFTH MONTH

1. Production: $15,500.
2. Series of sales samples of new line from kiln.
3. Conferences in connection with next year's program. Decided on actual work to be done.
4. Annual report covering the twelve months' activity and suggesting necessary plans for the coming year.

It will be seen that in addition, the regular business (which should not at this time be affected by the introduction of new lines) has been increased to the extent of $50,000. All the costs pertaining to the production of stock and orders on these lines would properly be charged to factory expense, but costs pertaining to research samples and the development of the lines are charged to the research department. But the research department is credited with the increase in business and prestige resulting from the success of these products. In summarizing results for the year, we find that the director has been responsible for the following activities:

1. The development of three new types of glaze.
2. The production of 500 research samples.
3. The production of five new lines of art products for the present market.
4. The direction of the production of orders on new lines totaling to $50,000.
5. The production of one new line of art products for the coming year.
6. The organization of a system for the development and produc-

tion of art pottery which fully perfected will operate with a minimum of loss and expense and with a greater efficiency in operation.

The costs involved for the given twelve months' activity would be distributed about as follows:

Total expenditure	$21,000
Equipment	5,000
Research and development including new glazes, sketch designs, working drawings, research samples, business trips and reports	5,500
Production of sales samples	7,000
Supervision of production	3,500

which means that $10,500 will be charged to factory production in addition to the regular factory expense involved in the production of orders on the new lines, and $5,500 for research and development.

Maintaining the same ratio of profit as the regular factory product (12%) on $50,000 of goods, this will amount to $6,000, a sum which in the first year of the establishment of the research work not only blankets the development expenditure, but will leave a small margin. In other words, the general manager has at little cost established an efficiently functioning, development department that is tied into the plant and engaged in the systematic production of new lines, and the direction of general production.

Assuming that the director has been supported to the extent that he has been able to increase the factory efficiency and adopted practices which have resulted in decreased losses, it can readily be seen that an investment like the one outlined can be still further productive, even within this stated time. Very few manufacturers give close attention to the many preventable losses. Few manufacturers know what these losses are. Lack of close supervision of workmen and even of foremen creates a condition where these losses are covered up and certainly not recorded. While it is true that the successful product must stand loss expense if the concern is to be operated at a profit, yet this does not solve the problem of preventable loss. It merely raises the price of the marketable goods and encourages a lax attitude among workmen and foremen.

Coöperation

It has already been stated that this is not a one-man activity. The results outlined could not possibly be attained unless the officials coöperated with the director in getting out the new lines. We started out by making a detached activity of the research department, but when the time came to produce the new lines, it is obvious that the director and the various foremen must work together. Also the business end of the concern must understand what is being done and why, and instructed to assist in every possible way. It is a simple matter to work out a program of activities, Chart Showing General Productive Results for First Year

Activity / Month	1	2	3	4	5	6
Organization	Install equipment	Install equipment	Selection of samples	Costs and sale prices	Preparation for orders	Preparation for orders
Organization reports	Factory conditions		Report to Gen. Mgr.	Cost estimates	Cost estimates	Cost estimates
Research program	Covering first 3 months			Production program		
Research reports	Decorative processes	Chemical exposition, etc.	Summary three months	Decorative processes	Production report	Production report
Research records	Necessary process records	Necessary process records	Process records	Process records	Process records	Process records
Sketch designs	50 sketches		15 sketches	10 sketches	5 sketches	10 sketches
Working drawings	12 shapes	12 shapes	10 shapes	12 shapes	10 shapes	5 shapes
Models	12 models	12 models	10 models	12 models	10 models	5 models
Molds	12 molds	12 molds	10 molds	60 molds	100 molds	150 molds
Clay wares	150 pieces	150 pieces	50 pieces	200 pieces	50 samples	50 samples
Glaze experiments	20 glazes	50 glazes	50 pieces	20 glazes	20 glazes	20 glazes
Color standardization		10 glazes	20 glazes	20 glazes	20 glazes	20 glazes
Decorated wares	50 pieces	50 pieces	50 pieces	100 pieces	50 pieces	25 pieces
Glazed wares	100 pieces	100 pieces	50 pieces	100 pieces	100 pieces	75 pieces
Research wares out of glost kiln		150 samples	250 samples	100 sales samples	Line B	Line D
Wares selected for factory production			25 pieces each Types A and C		25 pieces Line B	25 pieces Line D
Wares filed for future reference			350 pieces		175 pieces	100 pieces
Wares released for market				Lines A and C	Line B	Line D
Orders received						Orders $2,500
Amount factory production						
Research dept. expense	$2,000	$1,800	$1,200	$2,100	$1,800	$1,650
Factory production direct, indirect labor and material costs only					$500	$600

Chart Showing General Productive Results for First Year

Activity / Month	7	8	9	10	11	12
Organization	Labor and production program		Report on market			Conference next year program
Organization reports	Cost estimates	Cost estimates	Cost estimates	Cost estimates	Cost estimates	Cost estimates
Research program	Program for new lines			Outline for next year	Program next year	Program next year
Research reports	Production report	Production report	Chemical exposition, etc.	Production report	Production report	Production report
Research records	Process records	Process records	Process records	Process records	Process records	Process records
Sketch designs	10 sketches		20 sketches	20 sketches		
Working drawings	4 shapes	4 shapes	4 shapes	4 shapes	4 shapes	4 shapes
Models	4 models	4 models	4 models	4 models	4 models	4 models
Molds	150 molds	100 molds	100 molds	250 molds	250 molds	250 molds
Clay wares	200 samples	50 samples	20 samples	20 samples	20 samples	20 samples
Glaze experiments	20 glazes	20 glazes	20 glazes	20 glazes	20 glazes	20 glazes
Color standardization	20 glazes	20 glazes	20 glazes	20 glazes	20 glazes	20 glazes
Decorated wares	50 pieces	50 pieces	20 pieces	20 pieces	20 pieces	20 pieces
Glazed wares	150 pieces					
Research wares out of glost kiln	Additions to lines A-D	50 pieces	20 pieces	20 pieces	20 pieces	20 pieces
Wares selected for factory production	20 pieces A-D				20 pieces	
Wares filed for future reference	100 pieces	50 pieces	20 pieces	20 pieces	20 pieces	20 pieces
Wares released for market	20 pieces A-D				Line E	
Orders received	$4,000	$6,500	$9,000	$12,500	$15,500	$20,000
Amount factory production	$2,500	$4,000	$6,500	$9,000	$12,500	$15,500
Research dept. expense	$2,300	$1,700	$1,500	$1,200	$1,650	$1,500
Factory production direct, indirect labor and material costs only	$900	$1,300	$1,600	$2,100	$2,600	$3,000

but this can not be carried out if there are periods of delay due to no other reason than the attitude of reactionaries. Too often a research director has been given authority by the general manager, but this fact has not been made clear to the various officials who resent what they consider an intrusion and an unnecessary and additional expense. If this attitude results in the holding up of orders for supplies, in delaying shop practices, keeping the research work from the kilns, and the thousand and one other tricks known to the average official, the director of the activity has a hopeless task, unless he is aggressive and resourceful enough to force his program through; and in this case he can not do this without incurring the enmity of the various plant officials. While few directors desire such a condition, there is no other method of attack than to consider the activity as a purely impersonal one, and to carry out the program irrespective of opposition, after friendly coöperative measures have failed, and after it is definite that the general manager hesitates to give the desired authority.

The most satisfactory production policy is obviously that where the general manager will call the various executives in conference. These round table talks inevitably smooth out difficulties and practically eliminate jealousies, at least among interested and efficient officials. The jealous reactionary who is perpetually afraid of losing his job, and who will toady to the boss, while accepting no authority from any other quarter, and who will fiercely obstruct any development rather than have the present conditions changed, can not be removed too quickly. While his particular department may seem on the surface to be efficiently conducted, an impersonal investigation will quickly prove that this man is a very costly part of the organization.

Jealousy is the most costly and dangerous condition in a business organization. It should be stamped out as quickly as a fire. An official who is jealous of another and who fears the promotion of another is not only retarding general progress, but he is, as stated, inefficient in his own department.

There are so many specialized activities in the ceramic industry, each offering almost unlimited possibilities that there is no excuse for an official to be in a state of mind where he is afraid of the success of another member of the organization. Of course, the only solution is in the organization chart, and in the round table conferences of the general manager or plant superintendent, and these are not possible unless the general manager is sympathetic to such a condition.

To properly realize the results of efficiency in a perfectly coördinated organization, it is only necessary to compare the average organization in the ceramic field with those of other large national industries and business activities.

Organizations like the Standard Oil, General Electric, United States Steel Corporation, Victor Phonograph Company, Ford Motor Company, National Cash Register Company, Curtis Publishing Company, The Prudential Insurance Company, the various rubber companies, packing houses and the larger banking organizations could not exist if absurd and petty obstructions of jealous officials were allowed to permeate all through the plant. But the ceramic industry is choked with this condition, and it is one of the chief reasons why there is no single ceramic organization in this country that can compare in size or volume of business with the type of concern mentioned. Yet, the ceramic business is one of the most essential industries in the world.

It is doubtful if the industrial and business activities mentioned have practical and technical difficulties experienced by the potter. Yet there is no other industry so lacking in regard to efficient organization and expert direction. The technical problems are being efficiently worked out, and probably no other country possesses the high class of specialized technical help, but the biggest technical men or any other class of specialists do not make an organization, and they are not worth the salary of the least skilful workman on the plant if they are not in a position to use their knowledge and ability.

Size of Initial Organization

So far as personnel is concerned, the research department consists of the director, his personal secretary or record clerk and a student assistant. If the director himself can outline the program, make the designs and working drawings, molds and models, prepare the bodies and glazes, make and decorate actual samples, and if necessary, fire the wares, in short, if he is a thoroughly practical craftsman, no further assistance is needed until the activity is large enough to necessitate the director's attention in connection with production problems and increased research activities.

It is reasonable to assume that a person capable of directing a ceramic art activity should be personally able to carry out the various processes. If this fact is not recognized, it is easy to see that an initial organization must consist of three or four specialists, who would require a collective remuneration that would make a thoroughly efficient research organization in the average plant a questionable undertaking from a financial point of view—which is the only point of view a successful manufacturer can consider.

The Manufacturer's Interest in Research

There are a number of manufacturers who would be immediately interested in research work if they could be assured of reasonably tangible and marketable results within a stated period, and at a definite cost. A manufacturer who is buying a piece of equipment, or planning an addition to his plant knows what this is going to cost, and what the result will be. A research department is also an addition to and a part of the business organization, and consequently it should be subject to the same supervision and control as any other portion of the plant.

The manufacturer's chief interest, it must be remembered, is not in purely scientific research but in salable and profitable quantity production, consequently, he is not likely to give favorable consideration to a program that can at best only promise results in the future, and incidentally, that because of its highly scientific nature, can not at once be tied into the factory organization.

If a building is on fire, one can not wait for a perfect extinguisher to be developed, nor will any amount of theoretical work as to the cause of the fire serve any present result. It is a case for immediate action with the best equipment at hand. The scientific inquiry can accompany, or follow the active work of putting out the fire, and the results charted and used for future occasions.

The same condition exists in connection with the average present day ceramic art plants. From an organization point of view, they are in a chaotic condition, and nothing but a coördination of the various related essential activities with a directing head familiar with each branch of the work can develop the entire activity to the point where it is functioning as efficiently as is considered necessary in other large industrial undertakings.

Attitude of Research Director

In the organization described there is bound to be friction and opposition to a research program such as the one described. But the director of the activity must be broad enough to be able to interpret correctly this attitude. If he keeps the manager closely advised of the progress of the activity, and if he is frankly critical of his own work, no amount of opposition will be effective.

Fig. 2 illustrates the mental outlook of the efficient director, while Fig. 1 illustrates a state of mind that will react unfavorably in connection with any industrial activity no matter how much practical and technical knowledge the individual concerned may possess.

The actual results properly recorded and estimated in regard to costs will be the answer to any partisan criticism that may arise. And it can not be emphasized too strongly that the director must know at all times the costs in connection with the various activities under his direction.

I remember an instance where a very successful art pottery product was nearly discontinued because an office executive was not friendly to the development activities. The general manager was too busy to go into details, and in asking questions regarding the cost of the product, would accept a general answer without referring to the actual cost report. The cost clerk who knew nothing of the selling price would give evasive answers to the effect that "the product was costing entirely too much." The manager was gradually led to assume that this was a very unprofitable undertaking, and because of the lack of coöperation, nothing was said to the director. When the decision to discontinue the line was finally brought to the attention of the director, he presented the actual figures involved, and on investigation, it was shown that the undertaking was a most profitable one. If the director had not kept records of the cost of production, no amount of explanation or persuasion would have satisfied the manager.

The research director must expect opposition, and he must just as consistently react against this as he does against another unfavorable condition. If he can succeed in winning over the unfriendly element, so much the better for the organization.

A research organization is in its best sense an *influence*. To be most effective, the results will be obtained in such a way as not to be directly traceable to the director or any single individual. It is contended that in an organization as outlined where the director is working through the various specialists and skilled workmen it can be an infinitely greater productive force than a more or less detached department comprising a number of skilled specialists conducting independent investigations.

Industrial Training

Because of the lack of ceramic industrial schools, the program of the art pottery concerned must give serious attention to educational matters. Where special skilled help can not be obtained, it must be developed. The research director must be on the lookout for favorable material and must create a condition where interested workers realize that they have an opportunity for acquiring increased experience and consequent advancement. The human element is the most difficult of all the elements with which the potter has to deal, yet it is the most plastic and responsive where the working conditions are most interesting and favorable.

Loyalty to the Organization

An attitude of unquestioned loyalty to the concern and its officials should be taken for granted. It is an impossibility for a research or development man to be fully efficient unless he is interested in his work, and attached to his concern. Even mental reservations are harmful and distracting, and interfere with results. There are always difficulties and complications to deal with. These are the main conditions with which the research man must deal. They may affect the practical work, the working program, or the human element, or a combination of these.

Whatever the unfavorable condition may be, or however much cause there may be for dissatisfaction, it is up to the research man to put his work across in such a manner that it is as far as possible absolutely the property of the concern he is associated with. Too many ceramic specialists claim a paternal right to their particular processes and developments. They will fight to retain control of some essential part of the process.

If they leave the concern for any reason, they will produce identically the same things for the new concern. Such an attitude is either an out and out admission of inability to create new types, or it is deliberate dishonesty, because there is no question that the work done for the former concern is that concern's organization property.

If conditions are such that it is absolutely impossible for the research man to do productive work (and they would have to be very bad to legitimately admit this because it is possible to produce without the assistance of any individual on earth), then he should sever his connection and go somewhere else.

The individual who for any reason "soldiers" on the job, or develops an attitude of pessimism or distrust is a professional suicide so long as he is in that condition. Arnold Bennett made the statement that every man should see to it that his income increased at least ten per cent every year. It is obvious that this could not happen if there was no attempt to increase one's physical and mental equipment at the same rate.

In the final analysis, the researchist is a business man selling his wares to the manufacturer just as much as the manufacturer is in selling goods to the dealer. The dealer will not continue to buy from an untrustworthy manufacturer, neither will the latter for long retain the services of the research man who develops a disloyal streak because he is dissatisfied with conditions.

Some manufacturers have been criticised because they do not understand the difficulties under which the research men have to produce. Then it is the research man's job to demonstrate these difficulties and to show the manufacturer the possibilities.

The research man is a specialist just as much as the lawyer, the physician, and the banker. The manufacturer can not be expected to understand all the intricacies involved. If he did, he would not need the research man. But he can learn the fundamentals of the activity, and if the records are presented in a business-like manner, he can judge the results, and that is all the research man has a right to expect.

Business Training

Modern industrial research work is so tied in with business that it is essential that the research man have a first-class business training. Until a few years ago, this was practically an impossibility, and this is the reason why so few research men know anything about the commercial side of their respective industries. Such organizations as the Society of Mechanical Engineers, the Alexander Hamilton Institute, and the commercial courses in the various universities are catering to those professional fields where it is difficult to acquire a business training, so there is no longer any reason why the technical man should go through life limited in his opportunities because of this important essential in his professional equipment.

Coöperation with Research Organizations in Other Fields

The ceramic industry has not yet developed to that point where the various concerns would give favorable consideration to the establishment of a joint research laboratory. But this is no reason why organizations which are not competitive should not coöperate to the extent where process information could not be exchanged to mutual profit.

Art pottery must harmonize with its ultimate surroundings, therefore it is reasonable to assume that a friendly coöperation between the officials of an art pottery, a furniture factory, a textile plant, a carpet factory and wall paper house would result to the ultimate advantage of all concerned. There are many problems of design, style, color, etc., that would be worked out to a more satisfactory result. And there is no question that many decorative processes would be developed by the adoption of methods used in industries making an altogether different type of product.

American Encaustic Tiling Co.
Zanesville, Ohio

EFFECTIVENESS OF DIFFERENT METHODS OF MAKING ABSORPTION DETERMINATIONS AS APPLIED TO HOLLOW BUILDING TILE[1]

By Harry D. Foster[2]

ABSTRACT

The experimental work consisted primarily in selecting specimens from hollow tile from seventeen sources and saturating them for the absorption determination by (1) immersion in water at room temperature for various periods ranging from fifteen minutes to nine days, (2) boiling for various periods ranging from 1 hour to 5 hours and then cooling in water at room temperature for at least one hour, and (3) repeated vacuum treatments. The true porosity for some of the specimens was then obtained from the specific gravity and the per cent saturation reached by the various methods was calculated.

The results show that the five-hour boiling treatment gives results 1.2 greater than 72 hours immersion in cold water for the shale tile, 1.35 greater for the6fire clay tile, 1.20 greater for the surface clay tile, 1.25 greater for the mixed clay tile and 1.28 greater for an average of all tile. They also show that the cold water immersion treatment gives 73.5 per cent saturation, the boiling treatment 92.7 per cent saturation, and the vacuum treatment 97.0 per cent saturation.

In general the paper shows that the most consistent and practical way of determining the absorption of hollow tile is by boiling for five hours and then cooling for at least one hour before the saturated weight is taken.

Introduction

During the past two years a considerable amount of research work on hollow building tile has been conducted at the Bureau of Standards, primarily to obtain information on hollow tile as a fire retardant. Along with the fire tests, auxiliary tests are being made on representative tile to determine absorption, compressive strength, expansion, and resistance to freezing. This paper will deal only with the first one of the auxiliary tests named.

There are several ways of making absorption determinations as prescribed in specifications and building codes, as well as by more refined laboratory methods, some of which have been described in papers given before this Society. The question remained of determining the most practical method of making a determination for hollow tile that would also give fairly accurate and consistent results. It is evident that in an-spector of tile could not take the time for long saturation periods nor in all cases have the equipment or patience required by the vacuum treatment for saturating his absorption specimens. He would generally, therefore, be limited to two methods, namely, immersion in cold water for a period not longer than about three days and boiling the pieces from one to five hours and then allowing them to soak for a short period thereafter.

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[1] Published by permission of the Director, Bureau of Standards, Department of Commerce.

[2] Received June 22, 1922.

Since there is a considerable quantitative difference in results obtained by these two methods, the absorption of the hollow tile which are being studied was determined by each method and a comparison of the results obtained. Following this, the vacuum treatment was tried and later the true porosity of the specimens was calculated from their true specific gravity, and the per cent saturation obtained by the two former methods was found.

Method of Procedure

Some of the pieces on which the absorption determination was to have been normally made were taken for this study. They represented five shales, one marked "A," a strong shale from Indiana, two marked "B" and "C," blue Devonian shales from Iowa, one marked "D," a pure shale found in the vicinity of Louisville, Kentucky, and one marked "E," a mixture of two shales as found near Coffeyville, Kansas; six fire clays, three marked "F," "L," "M," from typical Ohio deposits, one marked "H," a very porous burning fire clay from Texas, and two marked "N" and "P," sandy New Jersey fire clays; three surface clays, one marked "O," a typical Chicago surface clay, one marked "Q," a Boston surface clay, and one marked "K," a New Jersey surface clay; and three kinds of mixed clays, two marked "G" and "S," mixtures of shale and fire clay, and one marked "R," a mixture of shale and surface clay. The percentage absorption was first determined by immersion for various lengths of time in water at room temperature and secondly, by boiling them for one, three, and five hours, respectively, and afterwards allowing them to soak for one hour in water at room temperature. This was followed by the vacuum treatment for saturating the specimens, and also by the determination of the true specific gravity which was done in order that the true porosity of the pieces might be calculated. By making this last determination it was possible to determine to what degree complete saturation was reached by the various methods which were used.

Selection and Preparation of Test Pieces

The pieces for the absorption determination were selected as follows: Three tile, one hard fired, one medium fired and one soft fired, were selected from each of the seventeen kinds of tile being studied. By means of a large stone saw these tile were then cut in two approximately equal parts, the cut being perpendicular to the length of the tile. One piece of each tile was then saved for a compressive strength determination to establish, if possible, the relationship between the absorption and compressive strength. The other piece was cut to give one complete cell from each tile so that a study of their resistance to freezing could be made. The pieces for the absorption work were then chosen from the remainder of the tile. Care was taken that one of the three pieces used was from the center web of the tile and the other two pieces from opposite shells. This gave three pieces, each containing from twenty to thirty square inches, which were free from the usual cracks that would be found in pieces selected after compressive strength tests had been made, and which were representative of the uniformity of burning of the tile. The wide variation of the absorption results obtained from pieces of the same tile show the necessity of carefully selecting more than one specimen if the information obtained is to be taken as reliable.

Immersion Absorption Tests

The first absorption tests were made by saturating the specimens by immersion in water at room temperature. The pieces were arranged in small groups of convenient size and each group was carried throughout the entire procedure as a unit. They were dried to constant weight in an electric oven, and then immersed in water in a large tray, the suspended weight of each piece being taken after immersion periods of fifteen minutes, thirty minutes, one hour, three hours, six hours, one day, two days, three days, and nine days. During all of these weighings the pieces were not taken from the water. The last suspended weight of each piece was carefully checked and immediately it was taken from the water, allowed to drain one minute, the surplus water wiped off with a wet towel, and its weight in air was taken. The percentage absorption at the various intervals was then found by the use of the following formula:

$$\text{Per cent absorption} = \frac{(S_a - S_w + S_{wp} - D)}{D} \times 100$$

where D is the dry weight of the specimen, S_{wp} is the weight of the piece suspended in water at the time for which the absorption is desired, S_a is the final weight of the piece suspended in air, and S_w is the final weight of the piece suspended in water.

By this method of obtaining the increments of absorption from the suspended weight in water the chance of irregularity in the results is more or less eliminated. As determined from the suspended weight in air irregularities are introduced due to variations in the amount of water on the surface of the specimen, even with great care in wiping off the surplus water. This method is especially suitable for absorption rate determinations or for determinations made for comparison. As a further precaution the pieces were all weighed on the same balance and to the nearest 0.05 gram.

The results of the immersion tests are given in Table I. The average rate of absorption for the fire clay tile, for the surface clay tile, for the shale tile, for the tile made from the mixtures of raw materials, and also the average for all tile has been plotted in Figure I. This shows that the increase in absorption is continuous throughout the nine days. It is clearly evident, therefore, that this would not be a consistent even though it may be a practical way of saturating specimens for the absorption determination.

TABLE I

RESULTS OF IMMERSION TESTS

Tile number	Percentage absorption when immersed								
	Minutes		Hours						
	15	30	1	3	6	24	48	72	216
	Shale Tile								
A	6.83	7.36	7.78	8.46	8.73	9.15	9.41	9.58	10.10
B	1.25	1.59	1.68	2.90	3.09	3.56	3.76	3.95	4.43
C	1.63	2.16	2.78	3.96	5.00	6.19	6.43	6.56	7.08
D	7.68	7.97	8.12	8.38	8.54	8.95	9.19	9.37	9.90
E	9.41	9.51	9.63	9.93	10.14	10.97	11.45	11.72	12.42
Aver.	5.36	5.72	5.99	6.73	7.10	7.76	8.05	8.24	8.80
	Fire Clay Tile								
F	7.04	8.10	8.78	8.63	8.86	9.08	9.40	9.58	10.16
H	9.41	9.65	10.08	10.55	10.67	11.76	12.22	12.55	12.94
L	4.60	5.43	5.50	5.61	5.74	6.12	6.44	6.97	7.43
M	4.91	5.22	5.32	5.52	5.65	6.18	6.43	6.64	7.24
N	5.44	5.82	6.09	6.77	7.05	7.65	8.05	8.40	9.52
P	6.06	6.90	7.50	7.85	8.16	8.76	9.31	9.73	10.53
Aver.	6.24	6.85	7.21	7.49	7.69	8.26	8.64	8.98	9.64
	Surface Clay Tile								
K	8.66	9.24	9.47	10.03	10.43	11.79	12.25	12.45	12.86
O	17.51	18.68	18.92	19.40	19.74	20.67	21.23	21.70	22.63
Q	4.86	5.03	5.24	5.62	5.76	6.07	6.27	6.35	6.57
Aver.	10.68	10.98	11.21	11.68	11.98	12.84	13.25	13.50	14.02
	Mixed Clay Tile								
G	5.81	5.93	6.01	6.22	6.31	6.75	7.03	7.26	7.91
R	7.71	7.86	8.06	8.49	8.76	9.42	9.77	9.88	10.25
S	4.26	4.99	5.26	5.46	5.61	6.02	6.25	6.36	6.88
	5.93	6.26	6.44	6.72	6.89	7.40	7.68	7.83	8.35
	Average for All Tile								
	6.63	7.14	7.49	7.87	8.13	8.77	9.09	9.36	9.94

Boiling Absorption Tests

The specimens used in the immersion tests were redried to constant weight which was always within 0.5 of a gram of the original dry weight. They were then arranged in small groups and each group as a unit was placed in boiling water and boiled first for one hour, a second time for three hours, and a third time for five hours. After each boiling period the water was quickly cooled to room temperature by means of a flow of tap water, the specimens being allowed to soak in this water at room temperature for one hour. Their suspended weight was then taken and from this and the data obtained from the immersion tests the percentage absorption was calculated by the same formula.

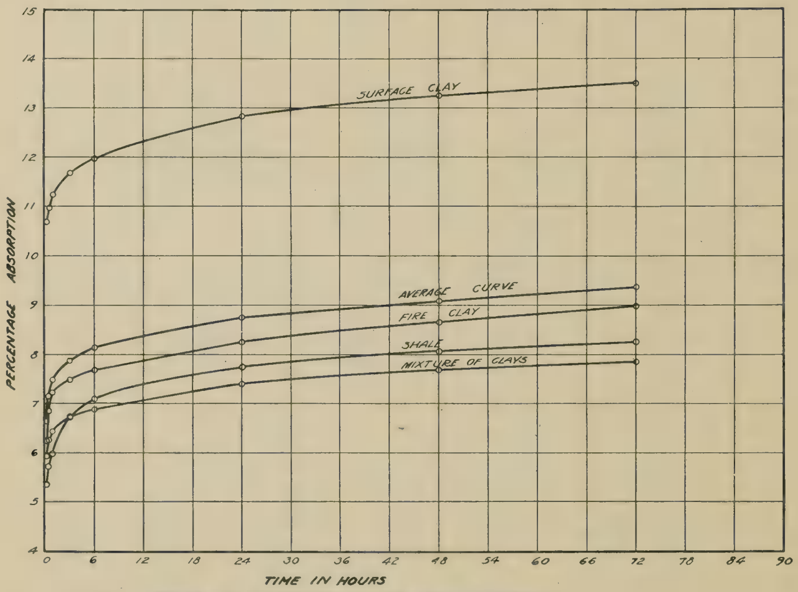

Fig I.– Showing rate of absorption by cold water immersion.

The results of the boiling absorption tests are given in Table II. A study of the average results as given in this Table shows that a more complete saturation was obtained by boiling five hours than by boiling one hour. The increased boiling, however, gave an increase in the percentage absorption of less than 0.3 per cent with all the tile except the surface clay tile in which case it ran as high as 0.7 per cent. It is doubtful whether the increased boiling period of five hours would be always worth while for hollow tile, but as a general procedure it may be advisable. We can then say that if the specimens are to be saturated by boiling they should be dried to constant weight, immersed in water, boiled for five hours, and then allowed to soak in the water for one hour after it has been cooled to room temperature before the saturated weight is taken.

TABLE II

RESULTS OF THE BOILING TESTS AND THEIR RELATION TO THE RESULTS OF THE 72-HOUR IMMERSION TESTS

Tile number	Percentage absorption when boiled 1 Hr.	3 Hr.	5 Hr.	Percentage absorption when immersed in cold water for 72 hours	Ratio 5-Hr. boiling 72-Hr. immersion
Shale Tile					
A	11.58	11.72	11.69	9.58	1.22
B	5.28	5.42	5.49	3.95	1.39
C	9.62	9.36	9.14	6.56	1.39
D	10.38	10.55	10.50	9.37	1.12
E	13.41	13.70	14.02	11.72	1.20
Average	10.05	10.25	10.17	8.24	1.26
Fire Clay Tile					
F	12.65	12.64	12.79	9.58	1.34
H	15.23	15.20	15.32	12.55	1.22
L	8.72	8.98	9.12	6.97	1.31
M	9.33	9.54	9.63	6.64	1.45
N	11.66	12.23	12.21	8.40	1.45
P	12.53	12.51	12.98	9.73	1.34
Average	11.68	11.85	12.01	8.93	1.35
Surface Clay Tile					
K	15.02	15.03	15.86	12.45	1.16
O	22.10	22.87	23.19	21.70	1.07
Q	8.17	8.41	8.57	6.27	1.36
Average	15.10	15.44	15.87	13.47	1.20
Mixed Clay Tile					
G	9.69	9.62	9.76	7.26	1.34
R	11.22	11.38	11.55	9.88	1.17
S	8.17	8.59	8.44	6.36	1.33
Average	9.69	9.86	9.92	7.83	1.25
Average for All Tile					
	11.45	11.66	11.78	9.36	1.28

Treatment by Vacuum Tests

In order to see whether the pieces which were studied could be more fully saturated and if so, how much, some were selected at random, re-dried and placed under a vacuum of 28 inches of mercury. After one half hour under this reduced pressure, water was admitted to the vacuum chamber and the pieces were allowed to boil for one hour. While the pieces were still immersed the pressure was raised to one atmosphere and the specimens were allowed to remain in the water and cool over night. On the next day this process was repeated and the percentage absorption obtained. The results of this treatment are compared with those of the boiling treatment in Table III. The apparent porosity of the pieces so treated was 26.51 per cent as against 25.34 as determined from the five-hour boiling treatment.

TABLE III

RESULTS OF THE VACUUM TREATMENT AND THE SATURATION REACHED BY THE VARIOUS METHODS

Tile number	Apparent porosity by 72-hour immersion in cold water	Apparent porosity by boiling 5 hours	Apparent porosity by vacuum treatment	True porosity by specific gravity	Percentage saturation by 72-hour immersion in cold water	Percentage saturation by boiling 5 hours	Percentage saturation by vacuum treatment
K	24.05	30.16	31.00	31.20	77.1	96.7	99.4
L	13.54	19.23	21.53	22.61	59.9	85.0	95.1
M	17.65	19.91	21.41	22.56	78.3	88.4	95.0
N	16.08	23.68	25.15	26.67	60.3	88.8	94.3
O	36.34	38.76	39.50	39.98	90.9	97.0	99.0
P	18.66	26.46	27.37	27.90	66.9	96.7	98.1
Q	16.48	21.37	21.82	22.50	73.2	95.0	96.7
R	20.06	23.18	24.28	24.68	81.3	94.0	98.4
Ave.	20.36	25.34	26.51	27.26	73.5	92.7	97.0

Although a higher result could be obtained by this treatment than by the boiling treatment, the increase was not considered large enough to make its use warranted for inspection work. For this reason no extended work was done by this method.

Porosity Determinations

In order to see how nearly the pieces were saturated the percentage porosity for some of the pieces as determined from the amount of water absorbed by the various treatments was compared with that determined from the true specific gravity. For calculating the percentage porosity from the data of the various absorption methods the following formula was used:

$$\text{Per cent porosity} = \frac{(S_a - S_w) + S_{wp} - D}{(S_a - S_w)} \times 100$$

where D is the dry weight of the specimen, S_{wp} is the weight of the specimen suspended in water at the time for which the porosity was required,

S_a is the final weight of the piece in air, and S_w is the final weight of the piece suspended in water.

The specific gravity necessary for determining the true porosity was found by the standard method as adopted by the American Ceramic Society.[1] Some of these determinations were also checked by means of the cement bottle.

With this data the true porosity of the specimens was calculated by the following formula:

$$\text{Per cent porosity} = \frac{(S_a - S_w) - \dfrac{D}{Sp.\ Gr.}}{(S_a - S_w)} \times 100$$

where D is the dry weight of the tile specimen, S_a the final weight of the piece in air and S_w the final weight of the piece suspended in water.

The results of these calculations are given in Table III. Assuming that all of the pore spaces in a piece could be filled this table also shows how fully the pieces were saturated by the various treatments.

Comparison of Results

The average results of this work have been summarized in Table II. As seen from this table the results from the boiling determination are always greater than those from the cold water determination, even when the immersion period is drawn out over a period of nine days. Quoting from "An Investigation of Tests of Iowa Shale Drain Tile"[2] by W. J. Schlick who did some similar work on Iowa shale tile, "The result of the boiling determination is equal to or greater than the result when the specimens are immersed in water at room temperature for 50 to 70 days."

Table II also shows that the boiling treatment gives results 1.26 times greater for shale tile than that obtained by 72 hours' immersion in cold water, 1.35 times greater for fire clay tile, 1.20 times greater for surface clay tile, 1.25 times greater for mixed clay tile, and 1.28 times greater for an average of all tile. As can be seen from the results of "B" and "C" our ratio of 1.39 for Iowa shale tile checks closely with the ratio of 1.40 as given by Mr. Schlick.[2] A part of the unfilled spaces probably were closed, while the remaining unfilled spaces were such that they could be filled only by long and repeated vacuum treatments.

In Figure II the ratio of absorption by boiling to that by cold water immersion is plotted against the absorption by cold water immersion as given in Table II. From this it is seen that the ratio varies in a direction inverse to that of the percentage absorption. As indicated by this curve, when the absorption, determined by the 72-hour immersion, is between 3 and 8 per cent, the ratio may be taken as 1.35, when it is between 8 and 16 per cent its value is about 1.25, and when it is higher than 16 per cent the ratio can be taken as 1.10.

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[1] *Year Book*, 48 (1921–22).

[2] *Bulletin*, **49**, Engineering Experiment Station, Iowa State College of Agriculture and Mechanical Arts.

The degree of saturation attained by the various treatments for some of the tile is shown in Table III. From this we see that an average saturation of 97.0 per cent was reached by the vacuum treatment, 92.7 per cent by 5 hours' boiling and only 73.5 per cent by cold water immersion for 72 hours.

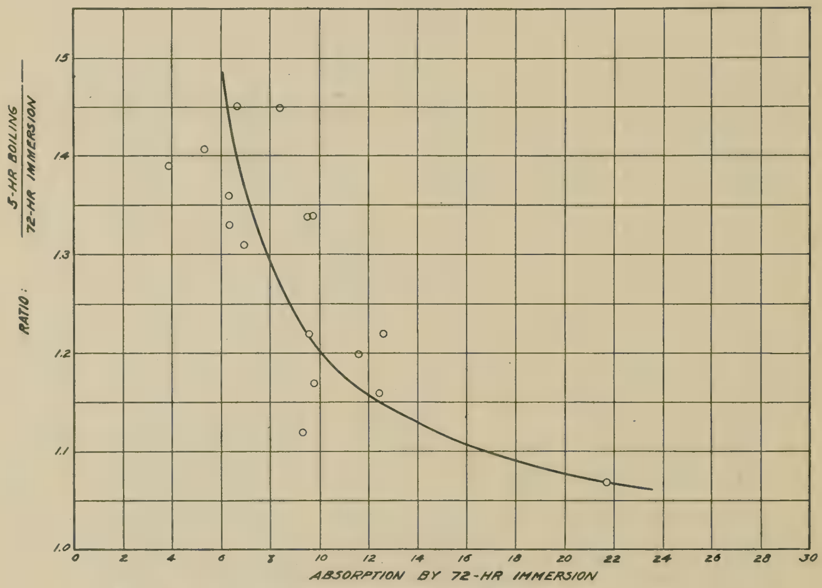

Fig II.– Showing the relation between the boiling and the cold water determinations.

Conclusions

From this work the following conclusions can be drawn:

1. Specimens for the absorption determination can not be fully enough saturated by 72-hour immersion in cold water to give practical and consistent results.

2. The vacuum treatment gives the most complete saturation of specimens, but due to the apparatus required would hardly be practicable for general adoption.

3. The best practical method for saturating hollow tile specimens for the absorption determination is by boiling for five hours, cooling the water and the specimens to room temperature, and then allowing them to soak at least one hour before the saturated weight is taken.

4. If the absorption determination has been made by 72-hour immersion in cold water at room temperature the result should be multiplied by the proper factor (average value 1.28) in order to compare it with results which have been found by the five-hour boiling method.

It should be noted that while these results may be true qualitatively they will not be true quantitatively for brick and other products where a specimen of a different thickness is used.

Acknowledgments

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Bureau of Standards
Washington, D. C.

INVESTIGATION OF DUST PRESS PRACTICE AS INFLUENCING FINISHED SIZES AND CRACKING

By H. Spurrier

ABSTRACT

Owing to erratic firing behavior, the factors affecting finished sizes of ware were investigated. Uneven distribution of air and water content and uneven density produced irregular shrinkage and consequent cracking and warping. The percentage of water in the clay as pressed is shown to be the dominant factor as affecting shrinkage.

Suitable loading of die corrected the differential shrinkage.

Experimental procedure is detailed. Influence of rate of pressing on porosity is set forth.

Introduction

Owing to rather serious losses in ware, consequent upon variations in finished size and cracking, it was thought advisable to make a survey of current practice, with a view to minimizing such losses.

Two pieces in particular were selected as being at once the greatest offenders and also as affording the best opportunity to obtain positive results.

One piece was known as a "T Rest," 12.48 inches in length and had a green weight of nearly three pounds, of somewhat simple design with no perforations.

The other known as a "Jack Panel" of rectangular outline possessed a number of ribs and a large number of perforations of various sizes and weighed about $3^1/_2$ pounds in the green state.

Great anomalies had presented themselves in regard to length variations of the "T Rest." Pieces coming from the same sagger showed variations of a quarter of an inch, consequently, one piece exceeded the maximum and the other did not reach the minimum size.

It was at once seen that these variations could not be charged to firing differences, because the differences noted amount to 2.2% of the total length of the piece, the normal shrinkage being 12.5%. A very simple calculation shows us that the variation calculated on the expected shrinkage amounts to 17.6% and this is, of course, impossible if it be considered as arising from firing alone and without some accessory cause, more particularly as the firing differences could not at most have exceeded 2 cones.

Causes of Variation

Accordingly, the likely causes of variation were tabulated in order that they might be followed up one by one, if necessary: Variations in (1) fired weight and effect of mass on shrinkage in various directions, (2) apparent density, (3) dry shrinkage, (4) loading die, (5) rate at which pressure is applied, (6) pressure per square inch, (7) water content of green dust, (8) physical condition of dust caused by temperature and time difference in tempering.

The two most nearly constant factors were: (1) the composition of the clay mix, (2) the firing.

It was impossible to develop any rationale as to size as the pieces came from the kilns, oversize and undersize coming from contiguous saggers, or even from the same sagger.

The fired weight showed irregular variations and nothing of value could be gained in this way.

The next step was to weigh and measure up a large number of pieces as they came from the dry rooms, while the pieces were in their original relative positions as placed by the pressmen. Here a variation of $8^1/_2$ per cent in weight and $^1/_8$ inch in length was found, and on tabulating the results some semblance of order was observed.

Eight skids or stillages were selected for this purpose. It was found that changes took place abruptly, measurements running uniformly for a while and then suddenly changing, suggesting a change in the clay itself.

As these pieces all came from dies of exactly the same length, the variations in length of the dry pieces could only be attributed to drying shrinkage which in turn must be considered as a function of the water content principally of the clay as pressed.

Mass, of course, influences shrinkages differently in various directions as is evidenced by a shrinkage on these "T Rests" of 10.57 per cent longitudinal and 11.25% transverse.

Design also influences shrinkage, but as these pieces were all alike this was considered as a constant factor.

The next step was to consider carefully the exact influence of water content of the dust.

It is obvious that if pieces are pressed from dust of varying water content the drying shrinkage will vary also, but a given increment in water content is not attended with a quite proportionate increment in drying shrinkage, the consequence being that such a piece will be proportionately more porous.

Experiment proved that the increased porosity of the dry piece, consequent upon high water content in the original dust, brought about increased fire shrinkage.

This is true whether the porosity is brought about by water drying out of a pressed piece or whether the porosity is due to air occluded in the pugging operation that precedes the working of bodies in the plastic form.

The differences in porosity of dried and unfired bodies is made easy of determination as follows:

The dried specimens are placed in melted paraffine wax in such a manner that they are not quite submerged. After thorough impregnation they are removed from the paraffine and allowed to become cold. They may then be easily sectioned for microscope examination.

This is best conducted with low power and using a vertical illuminator if an eye-piece grating is used, the actual proportion of voids can be easily ascertained.

Accordingly three lots of dust were prepared containing 16.2%, 16.8% and 17.6% of water, with which three sets of "T Rests" were pressed up.

In order to avoid the necessity of weighing the dust an attempt was made to measure the dust loosely filled into a pan and then struck off evenly with a stick. It was hoped in this way that a volumetric measurement might be made to act as a guide to the water content, but for the three moisture contents noted, the weight volume relation varied insufficiently to be used as a guide; the following figures were obtained when the dust was measured as above noted.

For dust with a water content of 16.2% were obtained 2 lbs., 4½ oz., and 2 lbs., 4½ oz.

For dust with a water content of 16.8% were obtained 2 lbs., 4¼ oz., and 2 lbs., 4½ oz.

For dust with a water content of 17.6% were obtained 2 lbs., 4 oz., and 2 lbs., 3½ oz.

It is interesting to note that under these conditions an increase of the percentage of water contained in the dust resulted in a slight reduction in the weight of a given volume, which in turn indicates that wet dust occupies more space than drier dust would do.

Such differences as these were considered entirely useless for the purpose of determining the suitability of a dust for a given piece of work.

TABLE I

DUST CONTAINING 16.2% MOISTURE

No.	Original weight	Dry weight	Dry length	Fired weight	Fired length	% Dry shrink.	% Fired loss weight	Per cent shrink.
1	2–10	2–3	10.906	2–2	9.953	1.68	19.04	10.28
2	2–13½	2–7	10.906	2–5	9.953	1.68	18.68	10.28
3	3–0	2–9	10.906	2–6	9.906	1.69	20.70	10.70
4	2–15½	2–8½	10.922	2–5½	9.875	1.56	21.05	10.99
5	2–14	2–6	10.922	2–5	9.875	1.56	19.60	10.99
6	2–13½	2–7	10.891	2–3½	9.891	1.83	21.90	10.84
7	2–13½	2–6	10.875	2–3½	9.875	1.97	21.90	10.90
8	2–14	2–7	10.891	2–4½	9.906	1.83	20.65	10.70
9	2–14½	2–6½	10.906	...	...	..	...	...
10	2–13	2–5½	10.891	2–3½	9.906	1.83	21.10	10.70
11	2–14	2–6	10.891	2–3½	9.891	1.83	22.80	10.84
12	2–13½	2–5½	10.875	2–3	9.875	1.97	23.00	10.90
			.047″	Max.	9.953			
	Max. Variation		3/64	Min.	9.875			
				Diff.	.078			
				Ave.		1.76	20.94	10.74

TABLE II

DUST CONTAINING 16.8% MOISTURE

No.	Original weight	Dry weight	Dry length	Fired weight	Fired length	% Dry shrink.	% Fired loss weight	Per cent shrink.
1	2–15$^1/_2$	2–7	10.844	2–5	9.844	2.25	22.1	11.27
2	2–12$^1/_2$	2–5	10.828	2–2$^1/_2$	9.828	2.39	22.4	11.40
3	2–14	2–6$^1/_2$	10.844	2–4	9.812	2.25	21.7	11.54
4	2–14	2–6$^1/_2$	10.844	2–4	9.859	2.25	21.7	11.12
5	2–15	2–6	10.859	2–5	9.859	2.11	21.2	11.12
6	2–14	2–6	10.844	2–4$^1/_2$	9.844	2.25	21.2	11.12
7	3–0	2–7	10.844	2–5$^1/_2$	9.844	2.25	21.8	11.12
8	2–15	...	....	...	...	..	...	...
9	2–14$^1/_2$	2–6$^1/_2$	10.859	2–5	9.812	2.11	20.5	11.40
10	2–15	2–6$^1/_2$	10.859	2–5	9.812	2.11	21.2	11.54
11	2–14	2–6	10.859	2–3$^1/_2$	9.812	2.11	22.8	11.54
12	2–15	2–7	10.844	2–5$^1/_2$	9.828	2.25	20.1	11.40
				Max.	9.859			
	Max. Variation	.031		Min.	9.812			
		$^1/_{32}$		Diff.	.047			
				Average		2.21	21.5	11.32

TABLE III

DUST CONTAINING 17.6% MOISTURE

No.	Original weight	Dry weight	Dry length	Fired weight	Fired length	% Dry shrink.	% Fired loss weight	Per cent shrink.
1	3–0	2–6	10.828	2–5	9.719	2.39	22.92	12.48
2	2–14	2–7	10.813	2–3$^1/_2$	9.719	2.53	21.82	12.48
3	2–15$^1/_2$	2–7	10.781	2–4$^1/_2$	9.734	2.81	23.16	12.25
4	2–12	2–4	10.797	2–1	9.734	2.67	25.00	12.25
5	3–1	2–7	10.813	2–6	9.734	2.53	22.60	12.25
6	3–0$^1/_2$	2–6$^1/_2$	10.797	2–5$^1/_2$	9.719	2.67	22.60	12.48
7	3–1$^1/_2$	2–7$^1/_2$	10.813	2–6	9.719	2.53	23.20	12.25
8	3–4	2–9	10.813	2–7$^1/_2$	9.734	2.52	24.04	12.25
				Max.	9.734			
	Max. Variation	.047		Min.	9.719			
		$^3/_{64}$		Diff.	0.15			
				Average		2.58	23.29	12.33

In these tables the loss in weight from green dust to dried pressed ware agrees pretty closely with the moisture determination made on the dust as shown at the top of each sheet, and when the loss that takes place in handling is taken into account, it is very close.

It is evident that water content is the chief factor in controlling shrinkage in ware made by dust press methods.

It is, of course, well known that if wet dust is used porous ware is the result. However, the increased drying shrinkage due to using wet dust is not proportional to the increase of water content and this unavoidably throws a greater burden on the fire shrinkage with consequent increased risk of cracking.

The following figures will make this fact clear:

Moisture content	16.2%	16.8%	17.6%
Drying shrinkage	1	1.037	1.0864
Total shrinkage	1	1.255	1.466
Shrinkage dry to fired	1	1.014	1.086
Per cent shrinkage dry to fired	8.98	9.11	9.75
Using 16.2% clay as 100 the ratios are	100	101.44	108.57

The explanation of these facts is to be found in the difference in specific gravity between the displacing water which is 1 and the displaced body which is 2.6. The great importance of this becomes evident when we realize that for every unit weight of water included, 2.6 unit weights of body are excluded to make room for it.

A further and important contributory factor is that the more moist the dust, the greater is the volume of occluded air.

The more moist the dust the coarser will it be, other things being equal, and consequently the greater will be the volume of air voids. In pressing such dust, as the two portions of the die come together, the piece is compressed from the outside inward, the exterior becomes close and non-porous before the inner portions feel the full effect of the pressure.

A distressing evil attending the use of wet dust is the swelling and frequent cracking of pieces so pressed, due to the expansion of the occluded air which can not find its way through the close outer surface as quickly as the pressure is released; this is especially noticeable in heavy pieces. This sets a definite limit to the safe rate of pressing.

It is interesting to note how positively the shrinkage follows the water content. The shortest piece of the batch containing 16.2% moisture is 9.875″ and the longest of the 16.8% batch is 9.859″, so we see a difference of .6% moisture has been sufficient to distinguish sharply between specimens pressed from the one or other of the two lots of dust. In like manner the shortest piece of the 16.8% dust is 9.812″ and the longest piece of the 17.6% dust is 9.734″. A total difference of 1.4% moisture has produced a difference of .141″ in length.

It was felt that this data was good enough to warrant a large size effort, consequently the usual number of "T Rests" were placed in the kilns. The moisture content of the dust used in making these rests was held between 16.1% and 16.3%. The result was very gratifying as not a single rest was rejected on account of size limits; this had never happened before.

Having the "T Rest" question settled, attention was addressed to the "Jack Panel" in which, in addition to all the usual shrinkage antics, warping and perplexing crackage were abundant.

Strangely enough this piece did not seem amenable to the established rule that had applied to "T Rests" and which had quite confidently been applied, but with indifferent results.

It became at once evident that other factors were complicating the case. Accordingly, in order to ascertain the approximate amount and distribution of the air in the green panels one or two were placed (separately, of course) in a bath of nearly boiling water; as the piece slacked down the relative amount of air could be estimated pretty well, and the mode of its distribution could be made out very nicely by the pattern of froth produced by the rising bubbles. Conversely the distribution of clay could be fairly well assessed.

This simple procedure of a hot bath for a sick piece of clay, is strongly recommended as a first aid in time of trouble—it reveals a great deal to the observant eye.

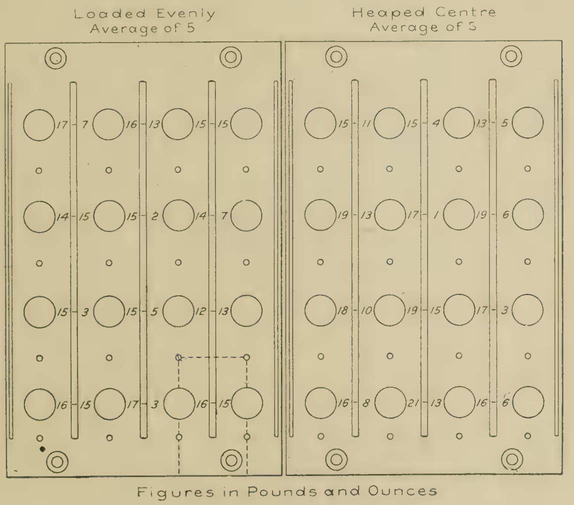

FIG. 1.

A very striking lack of homogeneity was displayed and a number of experimental lines were tried out simultaneously.

Several of the dried green panels were cut along the lines of the holes into five strips which were very carefully placed in sanded saggers and then fired. This procedure revealed two points of considerable interest: (1) There was a differential shrinkage, the inner members shrinking more than the outer ones; (2) The two outer or side members warped convex on the outside edges.

This indicated that the panels were less dense inside than around the edges which could only be interpreted as internal stress during firing which would inevitably tend to cracking.

Several fired panels were broken and the apparent specific gravity of the inner and outer portions was determined; the results of these determinations confirmed the idea of uneven air distribution; the average of a number of determinations showing:

Density of inner portion	2.3105
Density of outer portion	2.3415
Difference	.0310

As such a state of affairs seemed to involve the crucial point, an attempt was made to secure further corroborative evidence. Accordingly a number of the dried and unfired panels were sawed into strips along the lines of the holes and then these strips were sawed crosswise at the small holes, thus making a series of pieces rudely similar to cement test briquettes which were then broken in an improvised machine and the breaking strains plotted on a drawing of a panel.

The figures obtained fully bore out the indications of the two former tests. Although the figures for these breaking tests were not quite regular still the central portion of the panels showed a decidedly lower breaking strength than the outer portions of the panels.

The large number of pins in this die quite naturally caused considerable local differences in breaking strength, because wherever the clay is slicked along a hard surface it is always denser than where this is not the case.

Need was felt at this juncture of more positive information as to the actual movement of the dust in the die as it was felt that this might assist in formulating corrective measures. Accordingly, a die was loaded half full of dust, and then fine black cotton threads were moistened and laid quite straight between and parallel to the longitudinal rows of pins. The loading was then completed, the dust stricken off level and the usual pressure applied. The piece was then allowed to become leather hard, whereupon the clay was cut away from the upper surface in such a manner as to expose the black threads, the convolutions of which showed very plainly the trend of the dust movement which took place during the pressing.

Of course, it is reasonable to suppose that the transverse movement of the clay was greater than is indicated by the threads, because as the threads moved transversely a longitudinal shortening was necessitated which means that the thread must have been drawn through the rapidly hardening piece in a longitudinal direction thereby overcoming the consequent binding action, and this movement must have taken place at considerable speed. Wherever cracking had occurred which always took place at the sides, two points were noted, *viz.*, the ends were concaved and the sides were convexed, moreover, the cracks were always wider at the outside edges, which of course seems axiomatic, but of none the less significance.

In view of these several experiments and results it was reasoned that if the dust were heaped gradually toward the center of the die the clay would suffer initial compression in the center and ultimately sustain greater pressure at this area resulting in greater density there than would be the case in an evenly loaded die.

This conclusion was put into practice using the threads as before described, several panels so made abundantly bore out the correctness of this reasoning.

The stronger areas, as determined by five sets of breaking tests, had now been transferred to the center.

Conclusions

The average and individual breaking tests showed considerably higher values; the air distribution was more even and the flow lines of the dust in the die as indicated by the cotton threads showed that greater movement had taken place from the center to the sides of the piece. Ten pieces made in this manner were sent to the kilns, all coming out without a flaw and comfortably within the toleration limits, $^1/_{16}$ inch.

During the progress of these experiments some contributory work was undertaken designed to determine the influence of the rate of pressing on the porosity of the finished piece.

Porosity determinations were made upon a standard piece as then being pressed which gave a value of 3.42.

Pieces were then made at a slower rate of pressing which showed a porosity of .66.

Pieces were also made at a still slower rate of pressing which showed a porosity of .37 per cent.

After the porosity tests were made the pieces were divided into two parts and one part of each was ground down with carborundum and water upon a sheet of ground glass. These pieces made the porosity difference optically so obvious that it was considered worth while showing them here.

The outstanding feature noted in this investigation is the dominant influence exercised by the water content of the dust on the shrinkage characteristics of the fired piece. Not only is this true of dust pressed ware, but it applies equally to plastic or leather hard operations.

It is hoped that the methods adopted may be useful in helping others out of similar difficulties which are sometimes very exasperating and which lead to considerable financial loss.

Square D Co.
Peru, Indiana

THE EFFECT OF SOURCES OF PIG IRON UPON THE ENAMELING OF CAST IRON

By M. E. Manson

ABSTRACT

Cast iron made from certain "northern" pig iron blistered badly, while that made under the same conditions from "southern" pig iron enameled satisfactorily.

The use of "northern" iron results in castings with low content of combined carbon although the other constituents usually determined in cast iron were present in about the same quantities as found in cast iron made from "southern" pig iron.

Reducing the silicon in the iron made with the "northern" pig iron from 2.80 to 2.30% with a total carbon content of 3.30%, resulted in the elimination of blistering in the enameling operations. Experiments have indicated that cast iron of this type with combined carbon less than 0.15% will develop blistering. However, it has not been definitely determined as yet whether the blistering is due directly to this low carbon content or to the presence of some other constituent not generally determined in a chemical analysis of cast iron.

Micrographs are shown of various irons before and after enameling. While these show some differences, it has been impossible to detect the cause for the blistering by means of them. All blistering irons, however, show in the micrographs characteristic dark blotches which have not as yet been identified.

Comparatively little attention has been given to the chemical composition of cast iron which is to be enameled. The generally accepted view is that any kind of iron can be enameled, and foundry requirements govern the composition. At the plant where the writer is employed, in manufacturing enameled sanitary ware by the dry process, we have apparently discovered a cast iron which can not be enameled or at least can only be enameled with great difficulty.

Before the war, the company used "southern" pig iron for the major portion of the charge. That is, it was iron from furnaces in the Birmingham district. At that time this iron could be bought f.o.b. to Milwaukee for the same price as the so-called "northern" iron, which comes from furnaces in the Chicago region. In 1917, however, the "southern" furnaces stopped their practice of equalizing rates, and "southern" iron became considerably higher priced than "northern."

Naturally, it became desirable to use "northern" iron. Using "southern" iron, the company had adopted a specification which gave very good results in both the foundry and enameling room. A cupola charge of 2000 pounds consisted of scrap 900 pounds, "southern " iron 800 pounds, and "northern" iron 300 pounds. The pig iron was so chosen that the castings gave an analysis of silicon 2.80%, sulphur .090%, phosphorus .70% and manganese .50%. With total carbon around 3.20 to 3.30%, the combined carbon stood at about .35% This composition was maintained with very little variation, day in and day out, and this iron, though the pig iron might come from various companies, as long as the "southern" "northern" ratio was maintained, gave very satisfactory results.

When the attempt was made to substitute "northern" for "southern" iron, no change was made in the specification for the cast iron. The cupola charge consisted of 900 lbs. scrap, 800 lbs. "northern" and 300 lbs. "southern" iron. Our castings, as before, analyzed silicon 2.80%, sulphur .090%, phosphorus .70% and manganese .50%. Results in the foundry were about the same but when the castings were enameled, much trouble was experienced from pinholing. It was not a case of a pinhole here and there, which could be patched by the enameler. Whole tubs would be entirely covered with blisters.

Pinholes or blisters can be attributed to many causes, such as minute holes in the casting, poorly cleaned iron, underburned ground coat, etc., but in this case the cause was directly due to the use of "northern" pig iron in place of "southern." It was general, appearing on every piece, large or small.

An analytical investigation disclosed the fact that while the analyses of the two irons were identical with respect to silicon, sulphur, phosphorus and manganese, the carbons were different. Table I gives some typical analyses of the two irons:

TABLE I

Cupola charge	Silicon	Sulphur	Phosphorus	Manganese	Comb. carbon	Graph. carbon
800 lbs. southern 300 lbs. northern 900 lbs. scrap	2.92	.101	.69	.48	.30	2.92
	2.97	.088	.68	.52	.34	2.93
	2.80	.093	.71	.52	.30	3.04
	2.76	.080	.69	.53	.32	2.95
800 lbs. northern 300 lbs. southern 900 lbs. scrap	2.91	.107	.68	.51	.05	3.11
	2.70	.088	.69	.50	.11	3.20

Other things being the same, the percentage of carbon which will be in the combined form in a casting, can be controlled by the silicon. By increasing the silicon content, the combined carbon is decreased, and vice versa. Yet, with the same silicon in the second mixture as in the first, the combined carbon is very low. Our next step was to lower the silicon in the iron and we found that by carrying a silicon content in the casting of about 2.30%, with the high "northern" mixture, keeping the other elements unchanged, we obtained a combined carbon content of about .30%.

The reason for this difference in carbon is obscure. Several foundrymen have attributed it to the fact that "northern" pig iron is always higher in total carbon than "southern" iron. It is a generally accepted theory among foundrymen, that the effect of silicon on graphitization is governed by the total carbon content of the iron. The higher the total carbon in the iron, the lower the silicon should be, to give the same percentage of combined carbon. It is true that iron from southern furnaces contains less carbon than iron from northern furnaces, but when the pig iron goes through the cupola, it may either pick up carbon or lose it. In our own case, the average of the total carbon in the high "northern" mixture is not 0.10% over that of the high "southern" mixture.

I hardly believe, therefore, that the low combined carbon just mentioned can be attributed to the difference in total carbon content of the pig irons used. The fact should also be emphasized here, that molding and melting conditions in the foundry remained the same throughout, so that the difference in combined carbon can not be laid to a change in thickness of patterns or tempering of sand. We have used this high "northern" mixture for some time now, the castings having the composition, silicon 2.30%, sulphur .090%, phosphorus .70%, manganese .50% and have had fair success. Occasionally, we go back to the high "southern," high silicon mixture, for a few weeks, and there is no gainsaying the fact that the latter gives us better average results in the enameling operation. With the high "northern," low silicon mixture, most of the blistering has disappeared, but there is still an occasional epidemic of it. Every time this happens the combined carbon in the blistered piece is found to be below .15%. I have examined many blistered pieces and have noted but one exception to the above statement.

In the light of the foregoing facts one would be led to believe that a low content of combined carbon in iron would cause blistering, but it is hard to understand why this should be the case. The graphitic carbon has not been very much different in either of the two irons. Suspicion naturally attaches to graphite as the cause of blisters, because it can be burned to CO_2, a gas, and is capable of reducing certain metallic oxides in the enamel. In this case, though, the fact that there was little variation between the graphite in the two mixtures, seems to absolve it of blame. To get more light on the cause of these blisters, resort was had to metallography. We had no metallographic outfit ourselves, so that all photographs have been made by commercial laboratories.

Figures 1 to 6 all show iron which has blistered during enameling. When a piece blistered badly, it was broken up, analyzed, and a microphotograph made of the iron. It is of course understood that the piece of iron photographed had been freed from enamel, ground smooth, and etched.

Figure 1 is from a blistered sink. This specimen was etched with 10% nitric acid, which is too strong for cast iron. All other specimens are etched with $2^1/_2$% nitric acid. Figure 2 is from a blistered sink. There is very little of the blotching apparent in Fig. 1, but this was mistakenly photographed in cross-section. Fig. 3 is of the surface of a blistered tub, showing dark blotches. Fig. 4 is of a blistered sink, and gives a very good view of the dark blotches. Figures 5 and 6 are micrographs of two pieces of iron from the same pinholed tub. The exact location of a pin-

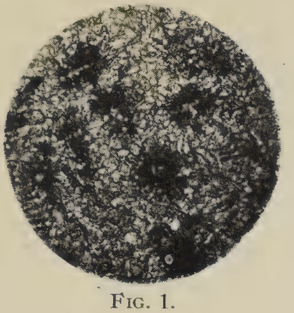

Fig. 1.
Si 2.91 P .68 CC .05
S .107 Mn .51 GC 3.11

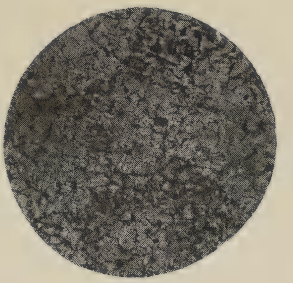

Fig. 2.
Si 2.17 P .67 CC .12
S .110 Mn .54 GC 3.52

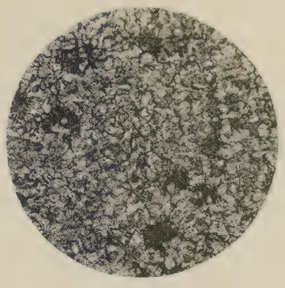

Fig. 3.
Si 2.31 P .66 CC .10
S .100 Mn .48 GC 3.50

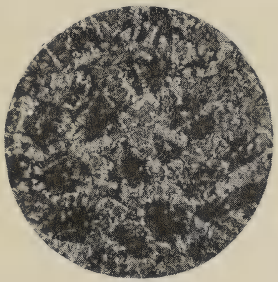

Fig. 4.
Si 2.55 P .65 CC .10
S .102 Mn .54 GC 2.76

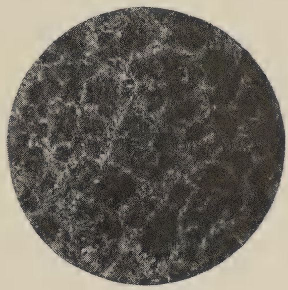

Fig. 5.
Si 2.47 P .69 CC .28
S .106 Mn .50 GC 3.23

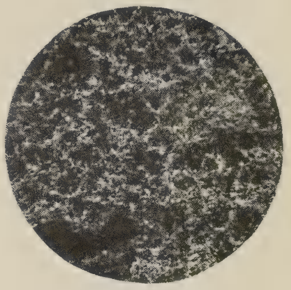

Fig. 6.
Analysis same as No. 5

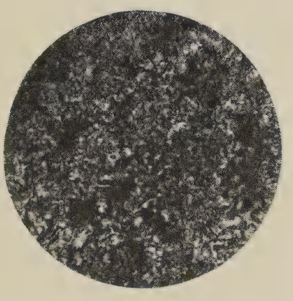

Fig. 7.
Si 2.55 P .71 CC .32
S .088 Mn .54 GC 3.04

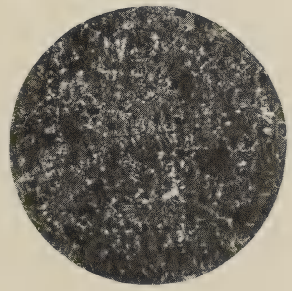

Fig. 8.
Analysis same as No. 7

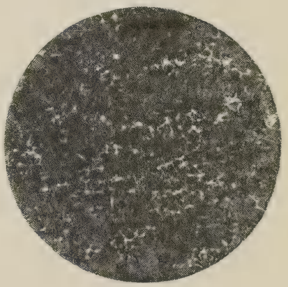

Fig. 9.
Si 2.41 P .66 CC .18
S .100 Mn .50 GC 3.10

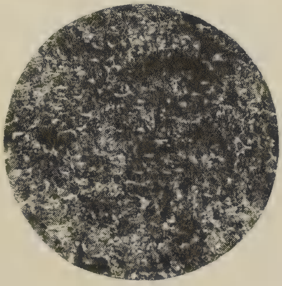

Fig. 10.
Analysis same as No. 9

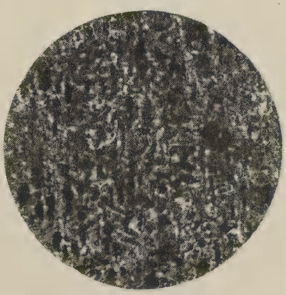

Fig. 11.
Si 2.75 P .71 CC .26
S .069 Mn .52 GC 3.06

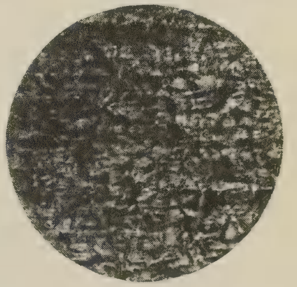

Fig. 12.
Analysis same as No. 11

hole was marked on the iron by three punch marks, and the photograph taken of this spot after grinding and etching. It might be said here that the iron underneath the enamel at these spots seemed absolutely sound to the naked eye. These two micrographs bring out the blotches very clearly.

These micrographs are all typical. Whenever this general blistering takes place, and a piece of iron which has blistered is ground, etched and photographed, the characteristic dark blotches appear in the photo. No metallographist has been able so far to tell me what these blotches are. They evidently have a direct connection with the blisters. When we can discover what they are, we will be a long way toward solving the difference between "northern" and "southern" iron.

This seems to be entirely a surface phenomenon. Whenever a micrograph is made of a cross-section, the blotches do not appear, even though the same piece shows them at the surface. Also, if a piece which has blistered during enameling, has the enamel knocked off and is sand-blasted again, it can be enameled without any blisters showing up.

Since in all of the specimens examined, except that represented by Figures 5 and 6, the combined carbon was low, it occurred to me that perhaps the enameling operation had the effect of lowering combined carbon. To settle this, several pieces were taken, broken in two, one-half enameled and the other not. Carbon determinations were made on both pieces. Analyses were also made of enameled pieces which had not blistered.

These data all indicated that no appreciable change in the carbon percentages took place during enameling.

Figures 7 and 8 represent two views of the same piece of iron. Fig. 7 was taken after enameling, Fig. 8 before enameling. This iron gave no trouble from blisters, and there are no blotches visible in either photo. I believe this could be called good enameling iron.

Another question which may be put, is whether these blotches exist in the iron before it is enameled, or are developed during the enameling. It is very hard to secure any data on this. We never know that a casting will blister until it has blistered. I have many times taken iron which I suspected, saved a piece, and enameled the rest, but have never been fortunate enough to find a piece in this way, which blistered. The nearest approach to it is shown in Figures 9 and 10. Fig. 9 is an iron which I suspected. The micrograph taken before enameling shows a very peculiar structure, very close grained, apparently. This piece when enameled had a very slight tendency to blister. Its structure after enameling is shown in Fig. 10, entirely different from Fig. 9, with a very slight evidence of blotches. This would indicate that the blotches are developed during enameling, but the evidence is too slight for much reliance to be placed in it.

Figures 1 to 10 all represent iron made with a cupola charge of 900 pounds scrap, 800 pounds "northern" iron and 300 pounds "southern" iron.

Figures 11 and 12 show two views of iron made with the high "southern" mixture in which the "southern" and "northern" iron weights are reversed.

Fig. 11 is the iron before enameling. Fig. 12 after enameling. There is a marked resemblance between these two, and Figures 7 and 8. Both are good enameling irons, although one is a high "northern" and the other high "southern" iron.

From the evidence of the micrographs, we doubt that combined carbon has a direct effect on blistering of enamel. Perhaps it is merely a coincidence that blisters are attended by low combined carbon. It seems probable that there is some element present in small amounts in "northern" ores, which does not occur in "southern" ores, or vice versa. The ordinary pig iron analysis only gives silicon, sulphur, phosphorus and manganese. Yet we know that the following elements are variously distributed among the different pig irons: chromium, calcium, cerium, nickel, copper, arsenic, and, no doubt, others. Might not one of these, if present in "northern" iron in appreciable amounts, have a simultaneous effect on the enamel and the combined carbon?

Rundle Manufacturing Co.
Milwaukee, Wis.

THE RELATIVE MERIT OF HEAT RESISTING ALLOYS FOR ENAMEL BURNING RACKS

By E. P. Poste[1]

ABSTRACT

Enamel burning racks fail by oxidation and warpage. Several metals have been studied with regard to oxidation and warpage at a temperature from 1700° to 1800°F. These metals are listed in the order of increasing warpage and increasing oxidation. Actual data is given and comparisons are made by means of a chart. Conclusions are drawn in terms of the choice of rack material for burning heavy and light ware.

Introduction

The troubles resulting from the oxidation and warpage of steel burning racks have caused enamelers to become interested in the various heat resisting alloys that have more or less recently come on the market. In view of the fact that in general these materials are high in price as compared with steel or cast iron, the question that naturally arises is, will it pay to invest the greater amount of money in racks of heat resisting metal in return for the longer life and better ware to be obtained. An effort to answer this question in a general way is the basis of this record.

There are two prime factors that contribute to the failure of a burning rack; warpage and oxidation. In general the former is a more serious trouble with heavy racks supporting large ware and the latter is more to be considered in the case of lighter racks. It was necessary therefore to study the action of the metals as to both of these properties at furnace temperatures.

Experimental

The following materials have been included in the comparisons which have been made: Basic openhearth steel, cast steel, cast iron, calorized steel, thermalloy, misco, nichrome, rezistal steel, nickel, monel metal, calite and hardite. These materials are listed by their trade names in view of the fact that they are all well-known products, the actual composition of many of which are not definitely known by the writer.

As representing fairly severe furnace temperatures the range 1700–1800°F was chosen for the tests. The atmosphere was that of a reasonably tight muffle.

In the warpage tests samples of metal 24 inches long and $^1/_2$ inch square were supported between supports 22 inches apart and placed in an experimental furnace maintained within the above temperature range. The less resistant metals sagged within an hour and were removed. Others kept their shape well after several hours. In either case the warpage was determined as sag at the middle in millimeters per hour.

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[1] Received July 20, 1922.

In the oxidation tests samples 2 inches long and $^1/_2$ inch square were used. These presented $4^1/_2$ square inches of surface and weighed approximately 70 grams each. They were placed in the furnace and removed at certain intervals. After cooling they were lightly pounded with a hammer to remove loose scale, it being assumed that in ordinary use racks would be punished mechanically so as to remove the majority of the loose scale. The samples were then weighed and returned to the furnace. A given sample was discontinued after it had shed a heavy coat of scale representing a considerable percentage of the weight of the piece.

Results

The results of the tests are shown in the following tables. In either case the metals are given in the order of their decreasing resistance. Warpage is expressed in millimeters sag per hour. Oxidation is expressed as change in weight from the original in units of one gram.

TABLE I

WARPAGE DATA

		Mm. per hr.
1	Calite	0.7
2	Hardite	0.7
3	Nichrome	1.0
4	Nickel	1.4
5	Rezistal	1.8
6	Thermalloy	2.5
7	Misco	3.5
8	Monel metal	4.5
9	Cast steel	5.0
10	Calorized steel	19.0
11	Steel (BOH)	22.0
12	Cast iron	101.0

TABLE II

OXIDATION DATA

Time—Hrs.	2	5	7	24	75	100	150	215	260
1 Thermalloy	0.00	..	+0.01	..	0.00	..	−0.02	0.00	−0.01
2 Hardite	+0.02	+0.03	..	+0.01	..	−0.01	..	0.00	−0.03
3 Nichrome	+0.01	..	+0.02	..	+0.02	..	−0.03	−0.03	−0.07
4 Rezistal,	0.00	..	0.00	..	−0.07	..	−0.33	−0.46	−0.21
5 Calite	+0.01	0.00	..	−0.03	..	−0.37	..	−0.41	−0.67
6 Nickel	+0.04	+0.10	..	+0.36	..	+0.53	..	−4.78	
7 Misco	+0.02	..	−0.07	..	−2.20	..	..	..	..
8 Calorized Steel	+0.01	..	+0.30	..	(*a*)	..	..	..	..
9 Monel Metal	−2.67	−8.49	..	..	..	..	..	..	..
10 Cast Steel	−3.75	−8.78	..	..	..	..	..	..	..
11 Cast Iron	−3.90	..	..	..	..	..	..	..	..
12 Steel (BOH)	−4.75	..	..	..	..	..	..	..	..

(*a*) One end of the bar was exposed steel. It shed a coat of scale at 75 hours. Much of the recorded change in weight was probably due to oxidation at the end. However, at 75 hours the calorized surface had blistered badly indicating a very immediate failure.

Conclusions

To facilitate an interpretation of the above data the values are plotted on Figs. 1, 2*a* and 2*b*.

In Fig. 1 the metals fall in three rather distinct classes as to their warpage at furnace temperatures. The first 9 can be considered as very good in their resistance to warpage; Nos. 10 and 11 as fair; and No. 12 as very poor.

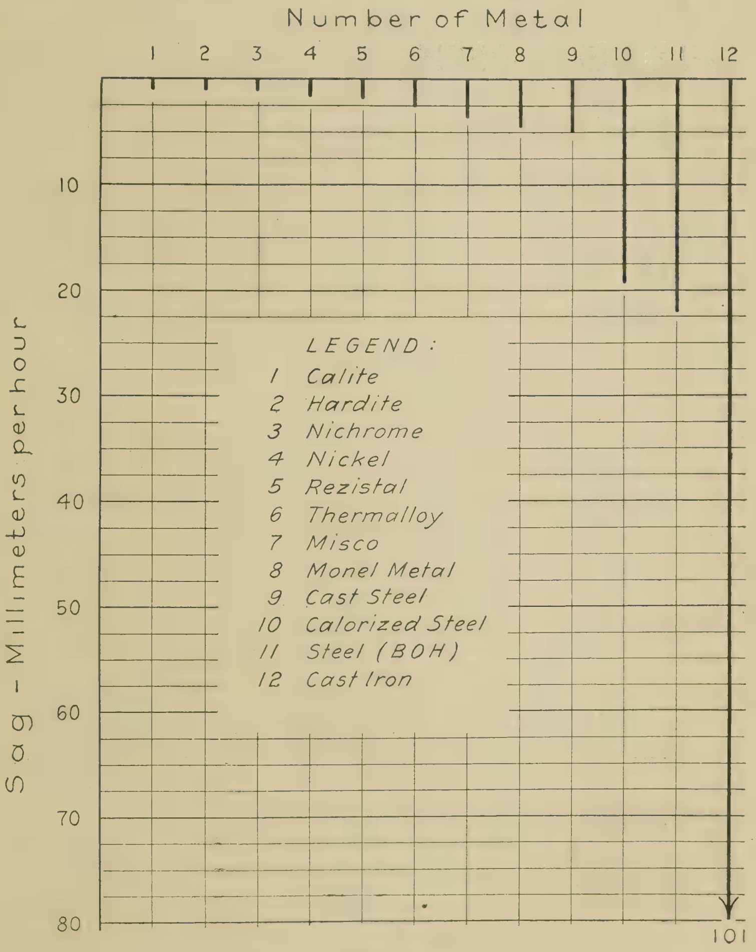

FIG. 1.

In Fig. 2*a* the metals group themselves in three general classes. Nos. 1 to 5 can be said to have good heat resistance; Nos. 6 and 7 fair heat resistance; and Nos. 9 to 12 poor heat resistance. The exact location of No. 8 is indefinite in view of the facts stated in the footnote of Table II.

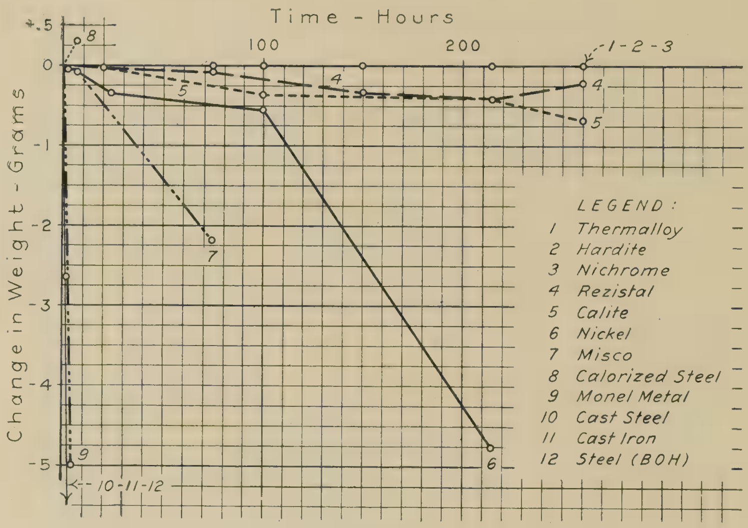

FIG. 2*a*.

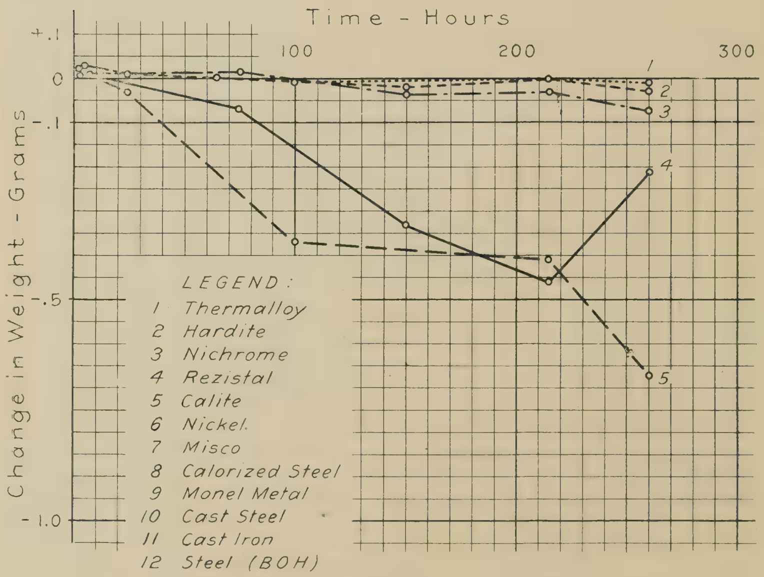

FIG. 2*b*.

Metals 1, 2 and 3 are of such high resistance to oxidation that they do not show up clearly on Fig. 2*a*. It will be noted that the values for 10, 11 and 12 are entirely beyond the range of the chart.

In Fig. 2*b* are plotted the metals which may be classed as highly resistant to oxidation. It will be noted that Nos. 1 and 2 are essentially the same, while No. 3 is definitely of lower resistance. The relative position of Nos. 4 and 5 is a matter of some doubt. The final heating apparently produced a rather severe oxidation on No. 4 which would have undoubtedly been followed by a considerable loss in weight, had another heating period been involved. Perhaps it may be concluded that Nos. 4 and 5 are of practically equal resistance to oxidation.

As a general statement of the points brought out in this study, it may be said that cast steel and all of the metals appearing above it in Table 1 show a reasonably satisfactory load carrying quality at furnace temperatures. With higher temperatures it is probable that the difference between cast steel and the stronger materials would become more pronounced.

As to resistance to oxidation it is obvious that cast steel is considerably better than steel and some better than cast iron. Only the metals included in Fig. 2*b* can really be considered as highly resistant to oxidation however.

The matter of the choice of a material to use in a burning rack would undoubtedly depend upon whether warpage or oxidation was the cause of greater difficulty. If warpage were the chief source of trouble the use of cast steel might be the most feasible procedure; on the other hand, if oxidation were the chief objection to be overcome it would undoubtedly be necessary to resort to one of the metals covered by Fig. 2*b*.

No effort has been made to include in this report the relative costs of these materials. Undoubtedly some of the more expensive ones would be quite out of the question for heavy racks, but quite feasible for light racks. The matter of cost can be easily determined by interested parties by communicating with the people putting the different alloys on the market. They are as follows:

Calorized steel	Calorizing Company of Pittsburgh, Pittsburgh, Pa.
Thermalloy	Electro Alloys Co., Elyria, Ohio.
Misco	Michigan Steel Casting Co., Detroit, Mich.
Nichrome	Driver Harris Co., Harrison, N. J.
Monel metal	International Nickel Co., New York, N. Y.
Rezistal	Crucible Steel Company of America, New York, N. Y.
Calite	Calorizing Company of Pittsburgh, Pittsburgh, Pa.
Hardite	Hardite Metals, Inc., New York, N. Y.

RESEARCH LABORATORY
ELYRIA ENAMELED PRODUCTS CO.
ELYRIA, OHIO

Discussion

BY M. E. MANSON:[1]—Mr. Poste's paper on this subject was especially interesting to me as I had done a small amount of work along the same lines at the time of the St. Louis meeting.

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[1] Received September 8, 1922.

At that time we had tried out several metals, testing only for resistance to oxidation and had found Thermalloy to be the only satisfactory one. Since then we have installed a set of Thermalloy bath tub grates, which have been continuously in a muffle at 1700 degrees F. So far they show no warpage, and practically no oxidation.

Laboratory tests have shown, however, that this alloy oxidizes rapidly at 2000 degrees F. On the other hand, two small samples of Calite, which Mr. Poste mentions, have shown practically no oxidation at 2000 degrees F. The manufacturers of Calite claim that it will withstand temperatures up to 2372 degrees F.

With such a metal available, at a reasonable price, it is possible that the day is not far distant when we will see enameling muffles built with metal bottoms.

Racks of a heat-resisting metal, which will neither oxidize nor warp, will be of great value in the sanitary enameling industry. They will not only show a lower cost per hour of service, but will lessen the rejections of warped ware, caused by warped racks.

THE CAUSTIC CALCINATION OF DOLOMITE AND ITS USE IN SORREL CEMENTS[1]

By G. A. Bole and J. B. Shaw

ABSTRACT

A method for calcining dolomite in which the pressure of carbon dioxide is controlled is described. Less than $^1/_2$ of one per cent of lime is liberated. Material was calcined in ton lots using external heating. Two types of retort were used: wrought iron and fire clay. Floors were laid from the material so calcined and physical tests made on the calcine to determine its availability as a stucco material.

The effect of time, temperature, and pressure of carbon dioxide upon three types of dolomite is brought out.

Dolomites are either double salts or solid solutions or mixtures of the two.

The effect of lime and silica is pointed out.

Dissociation, tensile strength, volume change, time of set, and weather test data are given.

Introductory

During the past few years the demand for a properly calcined caustic magnesia for use in the building industries has increased many fold. The oxide is used in two general ways: First, mixed with from 20 to 40 per cent of filler (asbestos, wood fiber, ground cork, etc.) and appropriate coloring oxides it is made into a composition flooring; second, mixed with 50 to 60 per cent sand and 20 to 30 per cent silex it makes an excellent stucco material. The general practice is to mix these compositions with sufficient 20 to 22° Bé $MgCl_2$ to spread properly when an excellent cement results.

A rather pure magnesite is necessary to produce a satisfactory material using the present burning practice due to the fact that all carbonates present are decomposed. Free lime even in amounts under 2 per cent is detrimental to the life of an oxychloride cement and in quantities over 3 per cent causes early disintegration. With this thought in mind and in view of the fact that high magnesia ore is not found near the centers of consumption, investigations were undertaken by the authors[2] to determine whether or not ore low in magnesia and high in lime, such as the dolomites, could not be used for the purpose. It is evident then that ores high in calcium carbonate must not be burned in such manner as to liberate free lime.

Effect of Time, Temperature and Pressure

Since the pressure of carbon dioxide in equilibrium with calcium oxide and calcium carbonate at temperatures as low as 650°C as shown by Johnston[3] is appreciable, it is evident that it is impossible to burn a dolomite at this temperature in any of the kilns in use at the present time for

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[1] Received April 25, 1922.

[2] Shaw and Bole, *Jour. Amer. Ceram. Soc.*, **5**, 311 (1922).

[3] Johnston, *Jour. Amer. Chem. Soc.*, **32**, 938–46 (1910).

burning magnesites, without liberating lime. The present general practice with magnesites is to burn in an updraft kiln, only a small amount of the present production coming from rotary kilns.

Aside from the above considerations there are two objections to burning the ore at a temperature as low as 650°C. First is the consideration that cements made from ores burned below 700°C are not as satisfactory as those made from an oxide burned between 700° and 800°C. This is not a generally recognized fact and the explanation is not clear. The cause should be investigated. An oxide calcined at 725°C or thereabouts seems to have different physical characteristics from that burned at either a higher or lower temperature. Illustrative of this fact, the following table shows the effect of temperature of calcination on a magnesite low in lime used in a stucco mix. The same relation was later found to hold when using dolomite mixes. (See Table V.)

TABLE I

	650°C	700°C	750°C	850°C
Time of set	$4^1/_2$ hrs.	3 hrs.	$3^1/_4$ hrs.	5 hrs.
Tensile strength (24 hours)	350	480	500	450
Weathering (per cent of original strength recovered)	63	80	80	72

The cement, the physical characteristics of which are given in the above table was of a (1 MgO-2 silex-5 sand) stucco mix, made up with 22° Bé $MgCl_2$ solution.

The time of set was in all cases determined by the Gilmore needle.

The weathering tests consisted of allowing the tensile strength briquettes to age 14 days and taking an average of the breaking strength of three briquettes as the dry strength. Six briquettes were then soaked in water three alternate days (24-hour periods), and three of the six broken wet. The others were allowed to dry out for two days in normal air and then broken. This average divided by the average dry strength at 14 days was taken as the recovered strength indicated in Table I.

The second disadvantage referred to is the time element in burning. Some dolomites will calcine very much more quickly at temperatures below 750°C than will others. A study was made of this feature of the burning problem with the results indicated in Figure 1. A sample of 0.5 grams under one atmosphere of carbon dioxide was heated in a small quartz side delivery tube in an electric furnace at the rate of 1° per minute until a temperature of 950°C was reached. The evolved carbon dioxide was collected over mercury in a graduated cylinder and the volume of gas evolved at each temperature observed.

A distinct lag appears in a time-temperature curve at 750°C due to the endothermic reaction $MgCO_3 \longrightarrow MgO + CO_2 - X$ calories in the case of dolomite No. 3, but No. 1 shows no distinct break. Bleininger and Emley[1] found this same break, but do not point out that it holds for only one type of dolomite.

Dolomite No. 1 was of the dense variety, No. 2 finely crystalline, and No. 3 was a highly crystalline stone. When later tried out in a semi-commercial way it was found that No. 1 could be calcined advantageously at 650 °C, while No. 3 dissociated so slowly below 750 °C, that it was not a commercial proposition to calcine below that temperature. It so happened that No. 3 was the most desirable one of the three on account of its pure white color and the ease with which it could be milled. The chemical analysis of the above mentioned ores indicated the following compositions:

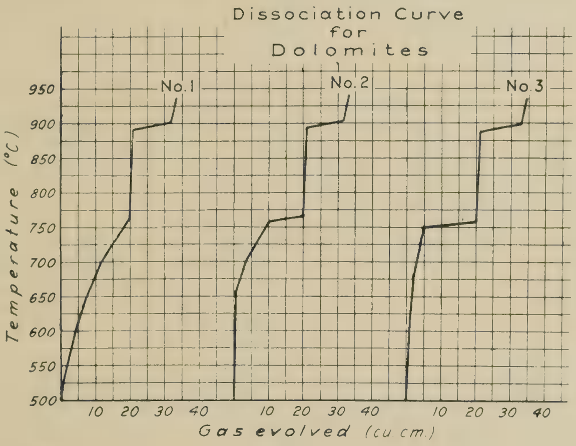

FIG. 1.

TABLE II

	No. 1	No. 2	No. 3
$MgCO_3$	39.40	46.20	43.32
$CaCO_3$	59.10	53.60	55.21
SiO_2	.35	.25	1.00
R_2O_3	.82	.65	.46

In light of the above data certain dolomites, it would seem, can be considered to be solid solutions from which $MgCO_3$ separates and dissociates progressively as the temperature is raised—CO_2 pressure being held constant—while others would seem to be a double salt with a decomposition temperature of 750 °C, while still others are a mixture of the two.

The above considerations are only tentative, but seem to explain this peculiar behavior of the dolomites better than any suggestion yet offered. The whole question is to be attacked microscopically with phase-rule interpretation.

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[1] *Trans. Amer. Ceram. Soc.*, **13**, 618 (1911).

Effect of Silica

It was further found that not all dolomites would make up to a satisfactory cement even when burned under the most favorable conditions of temperature—time—pressure. The unsatisfactory stones were found to be all high in silica. The analysis of a stone burning to a particularly unsatisfactory oxide was as follows:

CaO	MgO	SiO_2	R_2O_3	L.O.I.
29.15	20.00	6.10	.55	44.50

This stone was classified by the quarrymen as a water lime. Whether there is a calcium silicate formed at such a low temperature (under 850° C) seems to be problematical, but worthy of investigation. We have not been able to make a satisfactory cement from any ore containing more than 4 per cent SiO_2.

Method of Burning

The calcination of the ores was carried out in two different types of retorts; the chamber containing the ore in the one case being of wrought iron and in the other of a fire clay body. The gas-tight chamber containing the ore was so constructed as to give perfect control of the atmosphere within. A tube leading from the retort beneath a water seal kept the pressure of the carbon dioxide inside the retort at one atmosphere. The seal indicated when the calcination was completed by a slowing down and final cessation of evolved gas. The retort was heated externally by natural gas in a suitably constructed furnace. The temperature of the furnace was carefully regulated within 25° of any desired temperature. The two calcining chambers had a capacity of one-half and one and one-half tons, respectively. The time necessary for the calcination in both cases was from 10 to 12 hours.

In all about 15 tons of material was calcined at a temperature varying from 700 to 800°C. Floors were laid using this material together with suitable filler. The material set up in four to five hours too stiff for further troweling, was in use the second day after laying. These floors have been in service two years and are in perfect condition and giving good satisfaction.

Stucco

Realizing that an ore containing, when burned, only 28 per cent of MgO and as much as 70 per cent limestone was better suited for a stucco material than for flooring, where in many cases as high as 50 per cent of MgO is preferred in the final composition, experiments were undertaken to determine whether this material would make a good stucco which would resist the weather.

The weather test outlined above was applied to two dolomites widely different in physical characteristics. No. 1 and No. 3, whose calcination curves are shown in Table I, were chosen, together with a so-called Canadian magnesite with the following composition.

$MgCO_3$	$CaCO_3$	SiO_2	R_2O_3
78.05%	20.10%	1.60%	.70%

The ores were calcined at 750°C in a retort as described above and made up into a stucco mix. The results of the weathering tests are shown in Table III.

TABLE III

	No. 1	No. 3	No. 4
Tensile strength (14 days)	630	825	538
Wet strength	330	300	234
Recovered strength	486	410	535

The recovered strength of No. 4 was remarkable, No. 1 very satisfactory, while No. 3, in spite of its high dry strength, showed an unsatisfactory recovery.

The recovery of No. 1 and No. 4 is superior to 80 per cent of the "magnesite oxides" at present on the market made up in similar mixes. No. 3 would probably prove to be an unsatisfactory stucco material.

Overburning

It was thought desirable to determine whether the portion of the sample in direct contact with the hot walls was being overburned, so an inside cylinder was fixed within the retort in such a manner that the portion in direct contact with the hot walls could be removed separately from the portion in the center of the retort. A sample was calcined at 750°C in this manner and the free lime determined by the ammonium chloride-potassium permanganate titration process. It was found that the difference in the free lime was well within the experimental error inherent in the method. The amounts found were, respectively, 0.36 and 0.42 per cent. Physical tests were run on the two samples with the following results.

TABLE IV

		Sample from inner tube	Sample from outer tube
Time of set (final)		4 hrs.	4 hrs. 10 min.
Linear change		0.10%	0.12%
Tensile strength (averages)	24 hrs.	500	520
	14 days	825	800
Weathering (recovery)		60%	62%

From the above data it is evident that there was no overburning in any part of the retort.

Temperature Range

Since, as previously pointed out, it is more economical to calcine a dolomite at comparatively high rather than at low temperature, it was thought desirable to know the burning range of any given ore. Accordingly, three 20-pound samples were calcined at temperatures ranging from 700° to 825°C. The following table records the results of the tests:

TABLE V

		700°C	750°C	825°C
Time of set		4 hrs.	$4^1/_4$ hrs.	$5^1/_2$ hrs.
Tensile strength lbs. per sq. in. (averages)	24 hrs.	480	520	470
	14 days	765	800	805
	28 days	890	910	875
Linear change	At final set	Nil	Nil	.05
	48 hours	.05%	.06%	.12%
Weathering lbs. per sq. in.	Dry strength	765	800	805
	Wet strength	280	270	250
	Recovered strength	400	380	310

While the burning temperature did not show great effect on the tensile strength, it did indicate that the lower temperatures gave a better product, as indicated by the change of volume, time of set, and somewhat less clearly, in the weather tests. In no case was there more than 0.45 per cent free lime found.

Whether these results will be borne out in practice can only be proven by time, but the indications would point to the use of properly calcined dolomite as a source for magnesium oxide used in the stucco trade.

Summary and Conclusions

It has been pointed out that: (1) Dolomites can be calcined in such a way as to liberate the magnesium oxide and leave the calcium carbonate undecomposed by controlling the pressure of the carbon-dioxide.

(2) Dolomites having practically the same chemical composition may differ radically in physical constitution, and an explanation of the cause is offered, *i. e.*, that some dolomites are solid solutions and others double salts, while still others are a mixture of the same.

(3) The best temperature for calcining ore to be used in a sorrel cement was found to be approximately 725–750°C.

(4) Ores high in silica make an inferior cement.

DEPT. OF CERAMICS
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NOTE ON LADLE BRICK[1]

By D. A. Moulton

ABSTRACT

Review of Literature on Ladle Brick.—(1) American ladle in which it is stated no chemical reactions occur; (2) English ladle in which four or five chemical reactions occur simultaneously.

Fusion Point of Ladle Brick ranging from cones 17 to 30 depending on behavior of clay at temperatures below the fusion point.

Process of Manufacture.—Two processes, namely dry press and stiff-mud with preference for dry press. Modification of standard refractories is suggested.

Review of Literature on Subject

Refractory work[2] in a steel department begins with the lining of ladles used in transporting the molten metal from the blast furnace to a metal mixer, Bessemer converter, or to open hearth furnaces. A practical lining for such ladles consists of brick covered with a rammed mud cake made of six parts fire-brick grog, two parts clay, and two parts silica stone. This cake will last forty-eight hours continuous use, possibly longer, and comes out with the "skull." The temperature of blast furnace iron running into ladle is 2850°F, hence the lining must be refractory enough to easily withstand this temperature.

A charge[3] of forty tons of H. E. shell steel poured into a ladle with two casting nozzles left only fifty-six pounds or less of "skull" when the ladle was emptied. This ladle was unevenly preheated, and four or five reactions may be going on simultaneously in such a ladle, these reactions being exaggerated by the unevenly preheated ladle.

The reactions are oxidation, deoxidation, colloidal segregation, cooling, and definite change of phase (skull formation). This steel contained oxygen when tapped and had oxygen added to it by the ladle lining, so a test was run to determine the quantity of gas evolved by the ladle brick and the quality of the gas, when the sample was at red heat in vacuum by a Sprengel pump.

The following is chemical analysis of this brick lining:

Loss on ignition	0.20
SiO_2	54.00
Al_2O_3	38.78
Fe_2O_3	5.28
CaO	0.30
KNaO	1.10

One hundred grams of this brick sample only gave off 2.45 cc. of gas at 767 mm. at 15°C.

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[1] St. Louis Meeting, March 1, 1922.

[2] "Refractory Linings and Materials" by J. W. Haulman, *Blast Furnace and Steel Plant*, **5**, 159 (1917).

[3] "Properties of Refractories Used in Steel Production" by Allene Reynolds, *Trans. Ceram. Soc.* (Eng.), **17**, 385 (1917–18).

Clays Used in Ladle Bricks.—The ladle bricks made in this country are manufactured from No. 2 and No. 3 fire clays of which following analyses are typical.

	New Brighton Lower Kittaning	New Jersey	Aetna Mine W. Va.	Kentucky	Iowa	English
SiO_2	62.89	67.26	57.52	60.52	62.49	61.88
Al_2O_3	21.49	23.36	21.76	20.99	24.42	22.37
Fe_2O_3	1.81	1.63	3.41	3.41	1.45	3.00
CaO	0.38	0.25	0.60	0.21	0.29	0.32
MgO	0.56	...	0.88	0.14	0.08	0.44
Alkalies	0.29	0.65	3.60	2.85	2.41	NaO 0.36
						KO 1.42
TiO_2	1.03	...	0.83	1.10	1.19	1.14
Ignition	13.76	6.94	8.13	9.83	7.35	8.72

The range of fusion of clays used in making ladle brick and of the brick themselves runs from cone 17 to cone 30. The picture illustrates a dry press ladle brick, the upper half of which was not put into fusion furnace. The lower half was subjected to a heat treatment which caused a cone made from the same brick to fuse down. The brick was swelled some and had cracked.

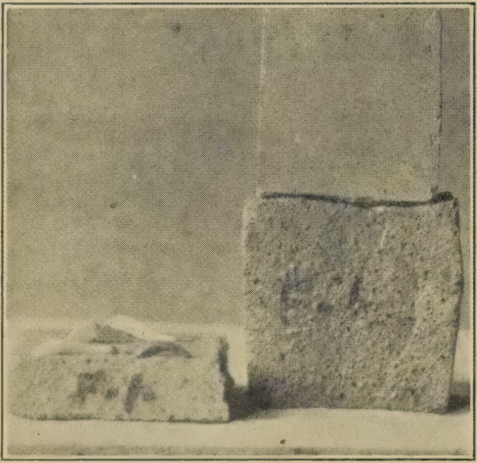

Fig. 1.

This brick in practice is giving about eleven heats with a mild steel low in carbon, using loose soil in bottom of ladle each time it is filled.[1] As high as 1000 heats can be obtained with a brick lining when the rammed clay lining is used to protect the brick.

The best ladle bricks have a fusion point of cone 26 and give 15 to 20 heats and are made without addition of any sandy material.

Methods of Manufacture

Ladle brick are made by both the stiff-mud and the dry-press process. The dry-press brick have given much better results in ladles.

Testing of Ladle Brick.—It is found that the standard tests for refractory bricks are too severe for ladle bricks and especially is this true of

[1] Information furnished by H. V. Smallwood, Purchasing Agent, Whitaker-Glessner Co., Portsmouth, O.

the slag test. The slag test, calling for exposure of five sides of the brick to the temperature of molton slag badly overfires the brick. The following heat treatment seemed to be best for slag test, using open hearth slags: Bring the kiln up to 2240°F, then put the brick into furnace; when 2350°F is obtained put slag onto the brick; hold at 2350°F for one-half hour. This produces a penetration averaging 0.15 inches for brick made of clay itself (mostly chemical solution), while in brick having an addition of sandy material, the penetration averages 0.30 inches, consisting of less chemical solution and more mechanical penetration filling very small crevices in the brick.

In testing with copper slags containing some metallic copper, the temperature of 2150°F is used, and the slag added and held at this temperature for three hours.

This copper test gives a penetration of 0.06 inch for brick of clay itself (mostly chemical solution), and 0.36 penetration in brick using sand rock with clay, this being mostly mechanical penetration.

The load test is also too severe for this class of brick.

The usual spalling test employed in testing high grade refractories, (cooling rapidly in water) is too severe. An air blast on hot end of brick gives comparative results and permits of grading of ladle brick in regard to ability to withstand spalling action.

Since large quantities of ladle brick are used every year, it is desirable to have special specified test for this particular type of refractories.

IOWA STATE COLLEGE
AMES, IOWA

I. THE USE OF PULSICHROME FROM A MANUFACTURER'S STANDPOINT

By Ernest Clark

ABSTRACT

I. Two papers setting forth the advantages of the pulsichrometer for applying glazes, followed by discussions. In the pressing room the use of the pulsichrometer gives a uniform appearance; rapid application and pleasing effect in one operation in slipping department; eliminates the necessity for re-burns in the kiln department; handled with greater speed in the fitting department.

II. The advantages of the pulsichrometer *versus* the old method of applying glazes are the better production of colors and elimination of the "human element." Closer coöperation is expected between the terra cotta manufacturer and the architect.

The advantages of the use of pulsichrome are many, and, so far, its disadvantages have to be discovered. As different experiments are tried from time to time, newer and better results appear, and it would seem as though a promising future lies ahead for the terra cotta manufacturer in this new method of applying the finish to the surface of the ware.

The first immediate benefits of the use of pulsichrome become apparent in the pressing room. The work turned out by a novice in the art of pressing after it has been sprayed by the pulsichrometer, shows as good a result as that turned out by a more experienced hand. The only necessities are that the ware be pressed out. The only finishing practically necessary is to remove the seam of the mould, and of course to see that the piece is straight and true. The pulsichrometer gives the ware a very uniform and pleasing appearance, which is all the more emphasized when the terra cotta is set, and the building completed.

In the slipping department further benefits are to be found. Under the old method of working, the slip, or enamel, was applied with an air brush and it was very essential that the workmen handling these air brushes should be highly proficient and skilful, so as to know when they had just the right amount applied. Again only one color could be applied at a time. With the pulsichrometer, any ordinary intelligent workman can be taught in a very short time to obtain a good result, for the machine gauges the amount of enamel applied, and, at the same time, the desired effect is obtained by the regulation of air pressure, thereby making the general effect consistent and similar throughout. Whereas it formerly took several operations to arrive at the final result in the slipping department, the pulsichrometer now obtains a better and more pleasing effect on one operation and the application is as rapid as with a plain enamel coating.

The greatest advantage of the pulsichrometer, however, is to be found in the kiln-burning department. Experience has shown that pulsichromed ware comes from the kiln 100 per cent good, making it unnecessary to have any re-burns at all, therefore delivering it to the fitting department, the job complete, and at a given time. Formerly, as is well known with straight enamels, the kiln burning department often got results which were unexplainable despite the fact that the greatest care and attention had been exercised in the burning of the kilns. There seems to be an unlimited leeway allowable in the burning of the pulsichromed ware.

In the fitting department the ware which has been under the pulsichrometer can be handled with greater speed in the assembling of the work than was formerly the case due to the fact it is unnecessary to shade the ware. Even in cases where a piece of ware has become fire-flashed all that is necessary to do is to sand-blast the surface lightly, and the effect of the whole becomes quite uniform. There is no such a thing as a crazed or blistered piece where pulsichrome has been used, and spalling is unknown. Pinholes will occasionally appear, as of yore, but the effect of the application of pulsichrome is such that the pinholes are neutralized to such an extent that the general aspect of the surface is not impaired thereby.

Minor chipping sometimes occurs in transit, and this is less noticeable on the building than in plain colors. In putting polychrome colors on pulsichrome pieces it is unnecessary in most cases to do any brushing off, which causes considerable saving in this department.

The American Terra Cotta and Ceramic Co.
Terra Cotta, Ill.

II. PULSICHROMETER vs. OLD METHOD OF APPLYING GLAZES

By L. M. Munshaw

For some time it has occurred to most of us who are striving to match or produce colors for terra cotta, that there must evolve some method of producing color and texture other than the old way of taking new colors and working them in with other colors to get a desired effect.

Many colors produced by the old method were obtained by the application of several speckles, sometimes as many as four, upon either the body or some undercoating. It required much work for the laboratory to prepare the numerous colors, as well as a great amount of work in their application. This application required a number of men experienced and proficient in this line of work because the amount of colors applied depended largely upon the pressure exerted by the thumb and fingers of the men on the hose carrying the enamel or slip. In working around ornament it was necessary to keep the hose well pinched together so as not to get too much color on the ornamental material. With the greatest of care considerable variation in color resulted, even at the best. This was inevitable because the hand naturally became weaker as the day progressed, allowing more enamel to flow through the hose than at the earlier part of the day. Then again the personal element had to be contended with, for no two workmen handled the hose in the same manner or with the same maintained finger pressure.

Now, by the use of the pulsichrometer, all this guess work and undetermined conditions are done away with, and as in modern machinery, the matter of "human equation" does not enter into the operation. Air pressure, size of hose, construction of nozzle plates, speed of machine, etc., are all recordable conditions and determine the tone color and texture of the result. Once a color is established, with this precise data at hand, it can always be duplicated with a certainty not reached by old methods, and the knowledge and control of these conditions make it possible to reduce the samples necessary to run.

To obtain a desired color and effect for matching a certain brick, stone, or granite, we take two or three of their predominating color tones and apply corresponding slips or enamels simultaneously with the pulsichrometer. In every case the result is a color that matches or harmonizes. In fact, so acceptable have been the results obtained by the pulsichrometer, that clients now ask for colors that *harmonize*, rather than for those which match or imitate.

Discussion

Mr. Tucker:—Do you vary your speed?

Mr. Ernest Clark:—In regard to varying the speed, I think there were some machines put out which ran faster than the uniform speed, but I think now they are all the same. Ours all run practically on the same speed.

Mr. McMichael:—I think we began using the pulsichrometer before the motor was developed up to the point it is now. We had difficulty with this motor, and since we were several thousand miles away, it was difficult to send for parts. We experimented with a flexible shaft on this motor. The first two shafts twisted in two pieces in about five minutes, but we finally secured a flexible shaft with which we had no trouble.

Mr. Albery:—Our experience with the pulsichrome machine has been the same as Mr. McMichaels's. We had been having a lot of trouble with the mechanical operation of the thing, probably due to the current that we used. The best machine that we have had is a one lung machine out of which we took one of the coils. Since then it has been running fine.

Mr. W. D. Gates:—Using this machine has cured many troubles we had in the old process in which the application varied not only when applied by different individuals but with the same man from day to day, for as his mood changed so did his manner of application.

A record of the setting of the machine can be accurately reproduced even after the lapse of a long interval.

Then too, the colors being all applied at once, all of the same consistency and wet, not only give spots of each color, but in their mingling to an extent give other tints; in the many cases even new shades of color. Its use, has saved us money, labor and annoyance and furnished great satisfaction to our customers.

MR. GLADDING:—In connection with this matter I would like to say that in the past year we have just completed two jobs using about a thousand tons of pulsichrome. We had very good results by using two glazes, one a brown, and the other a cream color, one containing tin oxide and the other containing chromium. The combination of these glazes where they happened to be built up in just the right combination will give a splash of pink, make a three color combination giving a very delightful effect. I was very much pleased with it.

MR. ALBERY:—I believe that several of the benefits claimed by Mr. Clark are benefits that are to be derived from the use of any mottled color regardless of the methods of application. Very little finishing is necessary on well-dressed terra cotta that is to receive a mottled color. Any mottled color will "pass" with a small variation which would ordinarily be objectionable in a plain color. Slight defects, such as pinholes, small blisters, small chips, etc., are not as noticeable in a mottled color as in a plain color.

I believe that the real benefits in the use of the pulsichrome machine are: (1) The new color effects made possible by its use. (2) The saving in the spraying department, where the work that would ordinarily require three experienced men can be done by one man of less experience.

MR. H. E. DAVIS:—I can agree with Mr. Clark that pulsichrome effects a saving in the pressing and finishing and also in the fitting departments. But as Mr. Albery has brought out, this is likewise true of any mottled color. However, there is one statement to which I must take exception: "There is no such thing as a blistered piece where pulsichrome has been used, and spalling is unknown." There is no machine, nor will there ever be one which will prevent blistering, as that is something which is entirely beyond the scope of any spraying apparatus.

As for spalling, I should like to ask Mr. Clark how he figures that this will be cured by the use of the pulsichrometer. As spalling does not usually become evident until a few years of weathering have had their effect, it may be quite possible that to date, spalling on pulsichromed terra cotta "is unknown," but I see no reason why, in the next few years, it may not be brought to light the same as on any of the usual enameled ware.

BY F. B. ORTMAN[1] (Communicated):—It would be very interesting if we could add to this series of papers on the pulsichrometer, a paper dealing with pulsichrome material from the architect's point of view. There is no doubt that pulsichrome material appeals instantly to a large majority of the architects who are anxious to develop something new in color and texture effects for building façades.

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[1] Received Aug. 31, 1922.

A very considerable proportion of the architects, at least those doing business in Southern California, frequently specify pulsichrome material and are already sufficiently well informed as to the character of the surface and texture produced as not to be satisfied with mottled and granite textures formerly produced by the method of superimposing one color upon another.

The force with which the particles of slip or glaze strike the piece is undoubtedly one of the most important features of the machine, as it results in a blending of colors and an enlargement of scale which can not be produced by any other method known to the writer.

The soft feeling produced by carefully selected colors applied with the pulsichrometer is eagerly sought after by most present day architects. Furthermore, the distinctive effect produced stamps the material at once as terra cotta being used entirely on its own merits, neither imitating other material nor capable of being imitated in other material. On the other hand, there are still some architects who do not take to the pulsichrome effect considering it somewhat of a fad and in keeping with the "jazzy" tendencies of the times, and insist that in a very short time architects will soon revert to the plain slips and glazes. Whether they will or not lies very largely with the manufacturers themselves. If they put out samples and material in clashing colors and loud unpleasing contrasts, pulsichrome materials will very soon be in discard. Too much care can not be exerted on the part of the manufacturer in submitting only those pulsichrome effects which are made up of pleasing natural blends of tints and shades rather than riotous hodge-podges of color.

Another objection sometimes raised is that the pulsichrome material prevents the proper registration or reading of the ornament. This, the writer believes to be more fancied than real. If the color contrast is not severe and if the modeler in executing this work bears in mind that the same is to be finished with pulsichrome material, the final result can be made even more pleasing by being rendered soft and harmonious. Here again the manufacturer must take a great deal of responsibility in not permitting pulsichrome finishes to be used on enrichment not adaptable to such a finish.

As regards the practical considerations surrounding the use of the machine in the plant, the writer's experience with the machine would not justify him in agreeing with all that has been said by the authors of these two papers. The machine has some very serious faults, the chief of which seems to be the unreliability of the small motors with which they are equipped. In our experience, it very rarely happened that the machine would hold up in continuous operation for very many days without having to be taken apart and rather extensive repairs and replacements made. Probably some of this trouble is due to the varying electric currents under which the machine is called upon to operate in different parts of the country, but nevertheless, this is a distinct weakness which the patentee should make every effort to overcome, in order to keep its popularity from waning.

The writer does not agree with Mr. Clark that the pulsichrometer makes the work pressed by a novice the equal of that pressed by an experienced man. It is true that very much less finishing is required when the pulsichrometer is used, but nothing in the way of surface finish can correct or cover up poor pressing.

Furthermore, in our experience, there has been no saving in time whatever in the spraying of pulsichrome material over the old method of spraying mottled ware, due to the fact that the time saved in the application of three slips simultaneously is considerably more than lost by the breakdowns that are constantly occurring in the pulsichrometer itself.

Neither can we agree with his statement that "pulsichrome ware comes from the kiln 100 per cent good, making it unnecessary to have any re-burns at all." It is true that the nature of the surface permits the use of considerable material having minor glaze defects such as slight crawls, pinholes, etc., that would not be permissible in plain ware, but there is still as much tendency toward variation in shade due to kiln burning conditions in pulsichrome ware as in any other ware, and this variation is always sufficient to make it absolutely essential that a certain amount of shading and selecting be done in the fitting department.

In general, the writer would say that the advent of the pulsichrometer was a distinct addition to the terra cotta industry in that it has enhanced the architects' opinion of the material by making it possible for him to secure effects not hitherto available. It has also helped in a small measure to solve some of the manufacturers' problems in getting out certain classes of work, but like most new machines, there is still a great room for improvement from a mechanical standpoint, and even when operating efficiently, it can by no means be considered a panacea for all ills of pressing, spraying and kiln burning departments.

THE EFFECT OF SOME FLUXES ON THE ABSORPTION AND TRANSVERSE STRENGTH OF A TERRA COTTA BODY[1]

By E. C. Hill

ABSTRACT

The results show the effect on the absorption and transverse strength of a terra cotta body by the addition of various material used as possible fluxes.

Introduction

In compounding terra cotta bodies, it is customary to control such properties as shrinkage, absorption and transverse strength by varying the amount of open and tight burning clays in the body, or by varying the amounts of porous grog. When it is necessary to lower the absorption and increase the strength of a body the tight burning clays are increased or vitrified grog is substituted for porous grog. The addition of other materials to the body to accomplish the same result is not practiced to any extent. The addition of some material to act as a flux in the body might be advantageous in some cases.

A small series of tests was made, using some of the common materials which it was thought might lower the absorption and increase the strength.

Table I

No.	Composition	Linear fire shrinkage	Per cent absorption	Modulus of rupture, lbs. sq. in.
	Clay Mixture	6.43	5.15	3474
	Body Mixture (no flux)	2.34	15.97	1518
1	5% Maine Feldspar	3.00	14.68	1486
2	10% Maine Feldspar	4.01	11.69	1905
3	5% Albany Slip	3.38	15.63	1590
4	10% Albany Slip	4.12	12.90	1732
5	2.5% Powdered Glass	2.81	14.84	1489
6	5.0% Powdered Glass	3.37	12.70	1687
7	2.5% White Lead	2.44	15.79	1372
8	5.0% White Lead	2.88	15.03	1461
9	1.25% Cryolite	2.80	15.54	1339
10	2.5% Cryolite	3.39	13.41	1426
11	1.25% Whiting	3.04	15.60	1618
12	2.5% Whiting	2.57	16.77	1503
13	5.0% Whiting	2.47	17.91	1545
14	2.5% Fluorspar	2.21	17.03	1275
15	5.0% Fluorspar	2.48	16.49	1326
16	1.25% Magnesium Carbonate	2.21	16.87	1269
17	2.5% Magnesium Carbonate	2.56	17.21	1240
18	5.0% Magnesium Carbonate	1.76	17.55	1152
19	5.0% Furnace Slag	2.26	15.68	1361
20	10.0% Furnace Slag	2.60	13.45	1407
21	2.5% X Flux	2.61	14.09	1685
22	5.0% X Flux	3.44	9.55	2032

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[1] Terra Cotta Division, St. Louis Meeting, Feb. 28, 1922.

The body used consisted of four clays and contained two parts of clay to one of porous grog. A sufficient amount of clay and grog for the series was prepared by grinding the clay and grog separately to pass a 16-mesh screen. Sixteen pounds of clay and eight pounds of grog were combined for each body, to which was added the flux. The whole was mixed by hand, water added and the mix thoroughly wedged.

Five trials 7 × $3\frac{1}{2}$ × 2 inches of each body were made from which the linear shrinkage was measured. Ten trials 8 × $1^1/_4$ × 1 inch of each body were made for determining transverse strength. All trials were fired at cone 6 in a terra cotta kiln.

The transverse strength trials were broken in an Olsen Shot Transverse Strength Machine with a 6-inch span. The cross-sections of the broken pieces were measured and the modulus of rupture calculated by the usual formula. The absorption was determined on the broken transverse strength trials, using pieces about 2 inches long. They were boiled two hours, completely immersed.

The results given in the following table are the average of five trials for linear firing shrinkage, ten for transverse strength and four for absorption.

Materials Tested

Feldspar.—Feldspar could be used as a flux in a body in amounts from five to ten per cent. Feldspars other than Maine could be had with a somewhat greater fluxing effect. Off-colored feldspars could be used for this purpose if they were finely ground.

Albany Slip.—This material is not as effective as feldspar. In these tests, it was ground to pass a 160-mesh screen. If ground finer, its effectiveness would likely be increased somewhat. It has a disadvantage of darkening the body color and increasing the drying shrinkage.

Powdered Glass.—This material is somewhat more effective than feldspar. If it could be obtained at a price that would warrant its use in terra cotta bodies, it would seem to offer better possibilities than any other material tested. It is likely that by grinding cullet or scrap glass at the plant, it would be available at a reasonable price. It would have to be ground to a fine mesh to prevent injury to workmen.

White Lead.—This material does not seem to be very active in the body, although it is an effective flux in glazes and slips containing feldspar. It would be too expensive for this purpose.

Cryolite.—This is an effective flux but too expensive for the purpose.

Whiting and Fluorspar.—Additions of whiting up to 5 per cent increase the absorption, but do not appreciably lower the strength, while additions of fluorspar increase the absorption and lower the strength. Whiting acts as a flux in glazes and slips containing feldspar.

Magnesium Carbonate.—Heavy magnesium carbonate was used. Additions of magnesium carbonate increased the absorption and lowered the strength. Magnesium carbonate is a very active flux in porcelain bodies at higher temperatures.[1]

Furnace Slag.—This material was obtained from the New England Slag Company through the courtesy of Mr. R. H. Minton. The lumps were broken up and ground to pass a 40-mesh screen. Addition of 10 per cent lowered the absorption, but did not appreciably increase the strength. Finer grinding would increase the effect of the furnace slag additions. The sample tested could not be used in a terra cotta body on account of the iron impurities, but it is said that slag free from iron, can be obtained.

X Flux.—This material was submitted for this purpose. It is a by-product containing soda, alumina, silica and about 4 per cent of iron. The composition is not known. It is very effective as a flux but could not be used on account of its iron impurities.

Conclusions

Any of the materials used that tended to flux the body would, no doubt, have been more effective if ground with the clay in a ball mill, but this method would have given a more intimate mixture than could be secured by the usual method of preparing terra cotta bodies in which the clay is ground in a dry pan.

The alkali salts probably have as great a fluxing action on terra cotta clays as any other materials that could be employed, but they can not be used on account of their tendency to form a scum on the surface of the ware. Insoluble materials, containing a considerable amount of alkali and which do not contain impurities that would discolor the ware, would appear to be the most desirable fluxing materials. In this series of experiments, these materials are feldspar, powdered glass and cryolite. The last mentioned is too expensive for this purpose. Since ordinary glass is more fusible than feldspar and contains more alkali, it would seem to be preferable to feldspar, that is if it is as economical to use.

Whether or not there is any advantage in using a flux in a body would depend largely upon the tight burning clays or vitrified grog available. Where these are available at reasonable cost, there does not seem to be any advantage in using a flux. By using a flux, however, a wide range of bodies are possible without the use of vitrified grog. If vitrified grog were to be used generally, it would be difficult likely, to obtain an adequate supply.

Conkling-Armstrong Terra Cotta Co.
Philadelphia, Penna.

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[1] Riddle, *Jour. Amer. Ceram. Soc.*, **2**, 812 (1919).

Discussion

Mr. C. W. Hill:—This is a subject which would seem to merit investigation. If a metallurgical flux were found which is suitable, one would of course have to be certain that its composition is fairly constant. Some fluxes vary considerably from batch to batch and trouble might arise from this source. In connection with the use of glass I wonder whether there is any danger in course of time of devitrification of the glass. If this took place and the glass were acting as a bond, the body would tend to disintegrate.

Mr. Minton:—Mr. Chairman, I thought that this by-product would be a very interesting thing to experiment upon for that reason. It would seem to me that the question of the fineness of the glass that is used ought to be considered.

Mr. C. W. Hill:—Of course, glass has a strong fluxing action on clay and it is possible that the composition after firing would be so changed that the resulting product would no longer have the properties of glass.

Mr. Hottinger:—Low-fusing clays can be used to produce denser bodies. However, they are usually red burning and will darken the bodies in which they are used. This is not always objectionable and some of these red burning fusible clays very often have a small iron content and do not color the body very much so that we have here a cheap source of material for hardening bodies. Many of these red clays have a very much lower softening point than the Albany slip clay used in Mr. Hill's experiment and will therefore have a much more powerful effect on the strength of the body. Many of the shales can be used for this purpose since they do not add any difficulty in drying or to the processing of the ware.

By C. W. Hill:—(Communicated). From a research standpoint it would be interesting to study the effect of these fluxes on the structure of the body. Possibly this could be done microscopically. It would also be interesting to study the action of the various fluxes on the individual clays and grit in the body in a laboratory way. Some indication of the action of the flux might be determined this way.

By R. L. Clare:—If it were Mr. Hill's intention to lower the absorption and increase the strength by this investigation, I think it would be much more practical to use low burning clays as the flux. I have found that clays, like the Brazil, Ind. clay, when added to a terra cotta body of the eastern type and burned to cone 6, are a very effective flux. In this manner, you are not adding a foreign non-plastic substance which materially affects the plasticity and working qualities of the body. From the factory standpoint, the introduction of an artificial flux, as suggested by

Mr. Hill, is liable to have a very serious effect upon the warpage of the body during firing. If 5 per cent of such a flux were added, the grog used would have to be reduced proportionately in order to maintain the same plasticity and working properties. It is not hard to predict the result of such a change on full sized burned pieces. A serious increase in warpage is bound to occur.

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ORIGINAL PAPERS

THE WEATHERING OF GLASS CONTAINERS[1]

By K. L. Ford

ABSTRACT

Stability in storage is a requisite of commercial glass. A white film or surface spotted with white patches is frequently observed on glass that has been in storage for some time. These weathering effects can be produced artificially by several methods which are given. Several factors, including humidity, have been found to influence the rate at which weathering takes place. Dipping in hydrochloric acid before packing retards weathering and paper properly used in packing is effective in decreasing the tendency to weather.

Three classes of weathering effects are given and illustrated with microphotographs. Experiments show that continued boiling removes the weathered surface.

The products of weathering consist of crystals of soluble salt or salts, principally sodium carbonate, and an insoluble film.

The lime, soda, and silica are found to have the same relative values in the weathered material as in the original glass, with the addition of certain amounts of carbonate, moisture, and dirt and organic material.

Weathering is largely dependent on solubility. Glass showing the greatest resistance to weathering proves equally resistant to action of water at temperatures and pressures above normal.

Condition of surface appears to influence the solubility. Alumina increases the resistance of glass to weathering. Sodium carbonate may exist in glass after manufacture and assist in weathering.

[1] Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce.

Introduction

Stability of Glass in Storage.—One of the requisites of commercial glass is stability in storage. Frequently the manufacturer or the dealer will find glassware, which has been held in storage for some time, covered with a white film or spotted with white patches. Attempts to wash the ware prove futile and a special treatment is necessary. The inconvenience and loss to the manufacturer who is required at times to hold in storage large amounts of stock reaches such proportion that weathering becomes an important problem. The Glass Container Association in coöperation with the Bureau of Standards is carrying out a study of this question tending toward the proper methods of handling the present type of commercial glass. The work has been confined principally to the composition of the film produced by weathering and a microscopic study of the resulting changes in the surface of the glass.

The occurrence of this breaking down of the glass surface is not limited to any special condition of storage, but appears to be very prevalent. In order to illustrate the extent of weathering, a few examples will be presented. Two cases representing the greatest difference in storage conditions are: (1) a beverage bottle stored in an open shed protected from the rain but subject to all atmospheric changes and (2) a druggist's bottle closed at the leer with a cork stopper, packed in a heavy pasteboard box, and stored in a modern well-ventilated warehouse. The period of storage was approximately the same. Both bottles showed on the inside a well-developed deposit which could not be removed by washing. Another sample of special interest is that of beverage bottles manufactured and stored in South America. These bottles were stocked in open bins subject to the action of the sun and rain. The composition of the glass was similar to that of the average American-made bottle. Weathering had developed to such an extent that large cracks were visible and several of the bottles burst when filled under pressure. Occasionally a druggist receiving perfectly clean ware from the manufacturer, which he places in a damp basement for storage, finds, when he opens the crates, severely weathered surfaces.

Water as Agent Producing Weathering.—Water is generally assumed to be the principal agent in producing weathering. This may exist as moisture deposited on the surface from the atmosphere or drops of water remaining on the surface after washing. Successive cycles of condensation by the heat of the sun or other methods of rapid drying appear to be quite effective in producing weathering. Such a condition is realized when ware, which has been washed to remove the products of grinding, is dried in a steam-heated room. In fact this drying process has been discarded by many manufacturers because of the frequent occurrence of white deposits and iridescent areas on the inner surface of the ware similar to the effect produced by weathering. Ware dried slowly is generally free from such trouble.

Several attempts have been made to produce weathering artificially. A simple but effective method is to place a few drops of water in the bottle, tightly close the bottle and allow it to stand for several days. Then by repeating the procedure a sufficient number of times a film of considerable thickness can be obtained. Similar results are obtained by breathing into the bottle and closing tightly. Treatment at about 60°C, in an apparatus with thermostatic control and with an arrangement for blowing steam against the surface of the glass each day until a condensation was produced, and then allowing the surface to dry out, developed a distinct film within three weeks. Glassware stored in a special room where the humidity was very high and the temperature constant has exhibited deposits within a month, while the same ware stored in a dry room has shown no evidence of weathering even after a period of five months.

The manufacturer has found by experience that certain factors within his control appear to influence weathering. It has been observed that empty wooden boxes, stored in the open, when they become saturated with moisture during rainy periods, and then filled with ware and placed in dry storage, bring about weathering sooner than dry material.

Hydrochloric Acid Dip Retards Weathering.—Certain commercial glass products are dipped in hydrochloric acid before packing, to retard staining or weathering. Tests carried out at the Bureau and the experience of several manufacturers prove that this treatment decreases the tendency to weather. This is not, however, an absolute preventative, for tests have shown that after a sufficient period of exposure weathering does occur.

Paper Retards Weathering.—The packing of glass was considered a possible factor in weathering. The materials used in the construction of the pasteboard box were held directly responsible. Investigation of composition indicates that no injurious effect could be produced by any of the materials of the pasteboard box or of the paper in which the ware is wrapped. On the contrary, paper properly used has proved a distinct advantage in preventing weathering. Window glass is always packed with paper between the glass. While the principal reason may have been to prevent scratching of the surface, yet it has been observed that wherever the paper fails to cover the glass, weathering will take place in course of time.

Types of Weathered Glass

Weathered glassware differs considerably in appearance and seems to fall into three separate classes. This division is purely arbitrary. Class I (Fig. 1) is usually observed on ware stored in the open or for considerable

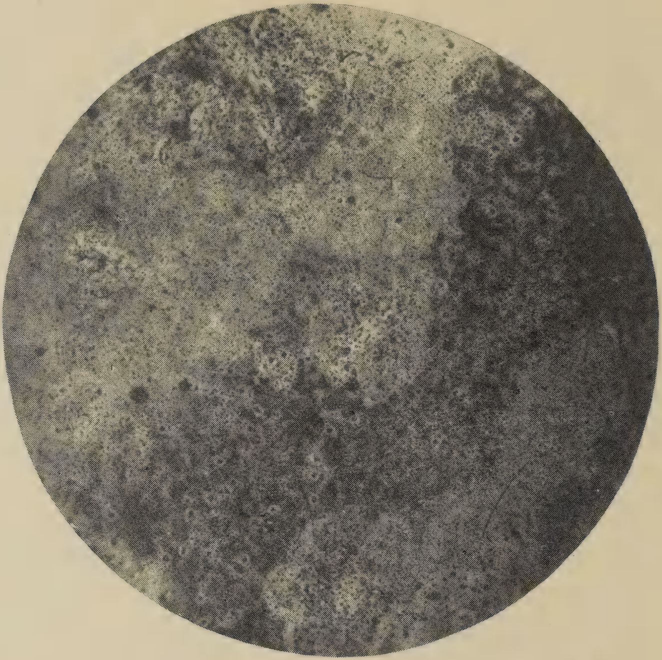

FIG. 1.—Weathered surface of green bottle glass, Class I. Mag. × 10.

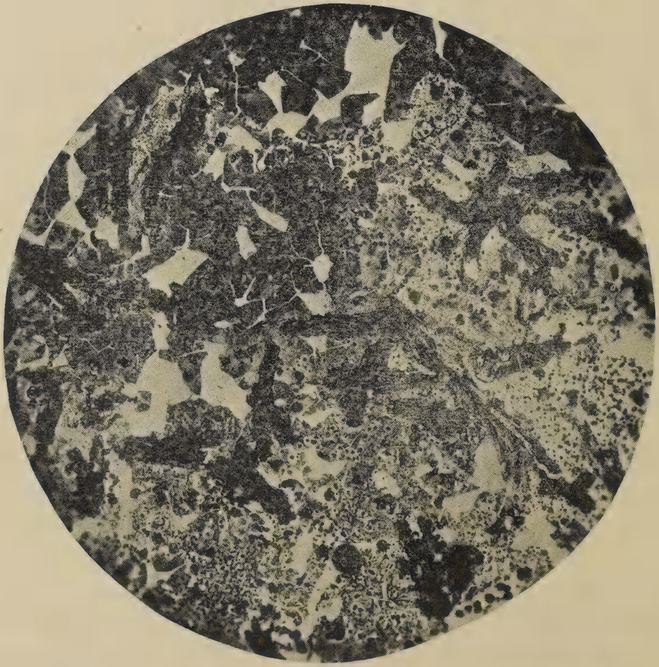

FIG. 2.—Advanced stage of weathering, Class I. Mag. × 3.

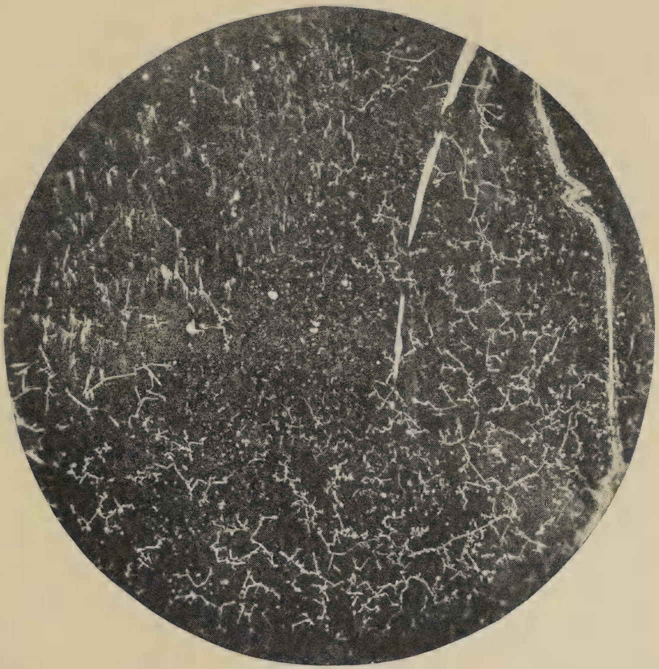

FIG. 3.—Weathered glass, Class II (photographed with reflected light). Mag. × 3.

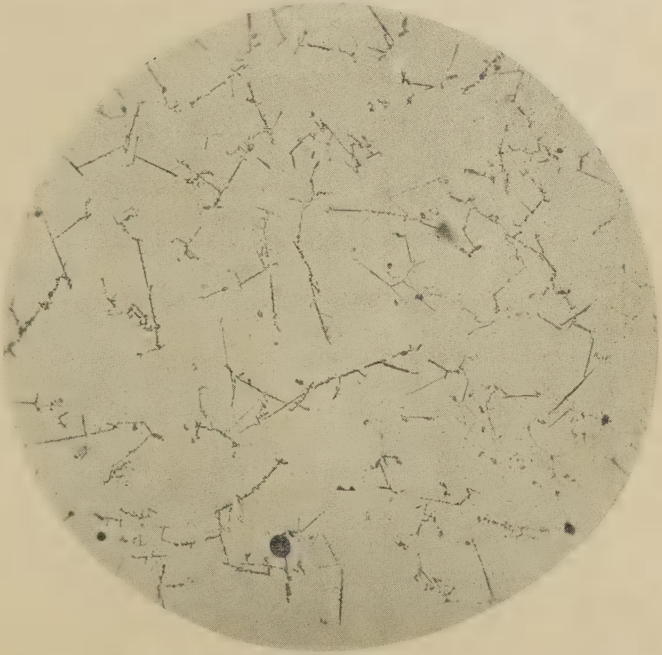

FIG. 4.—Weathered glass, Class II (photographed with transmitted light). Mag. × 10.

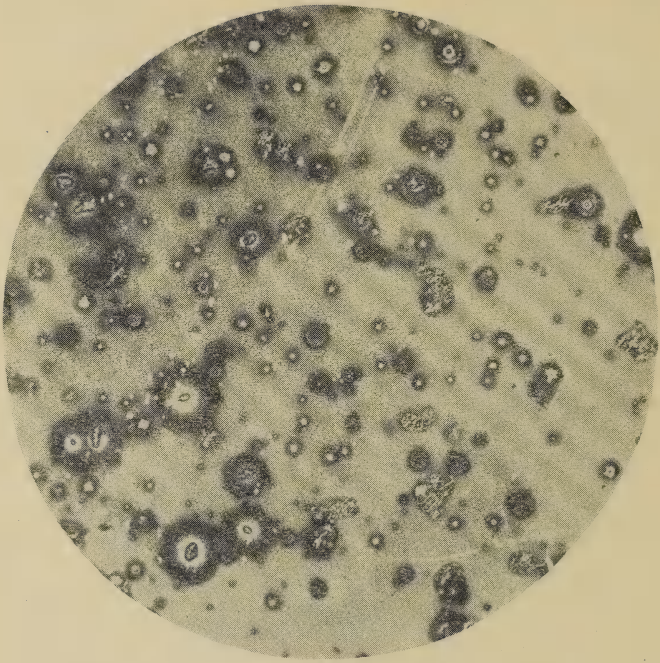

FIG. 5.—Weathered glass, Class III. Mag. × 3.

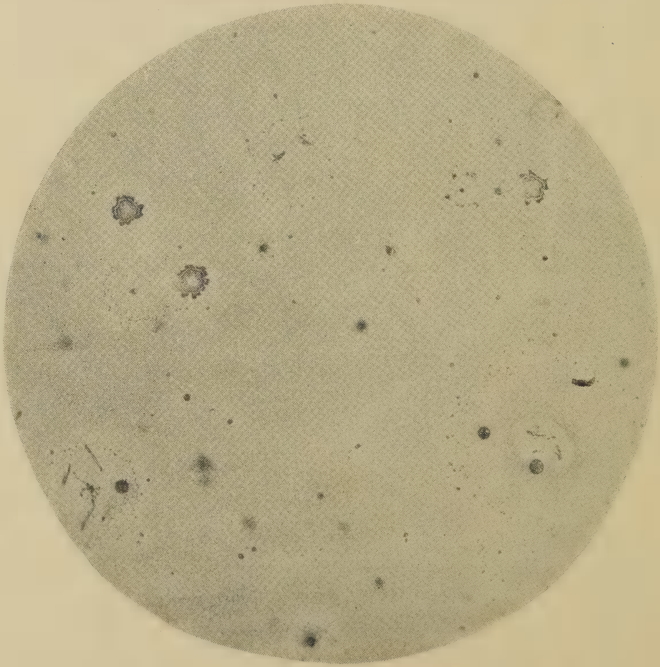

FIG. 6.—Weathered glass, Class III. Mag. × 10.

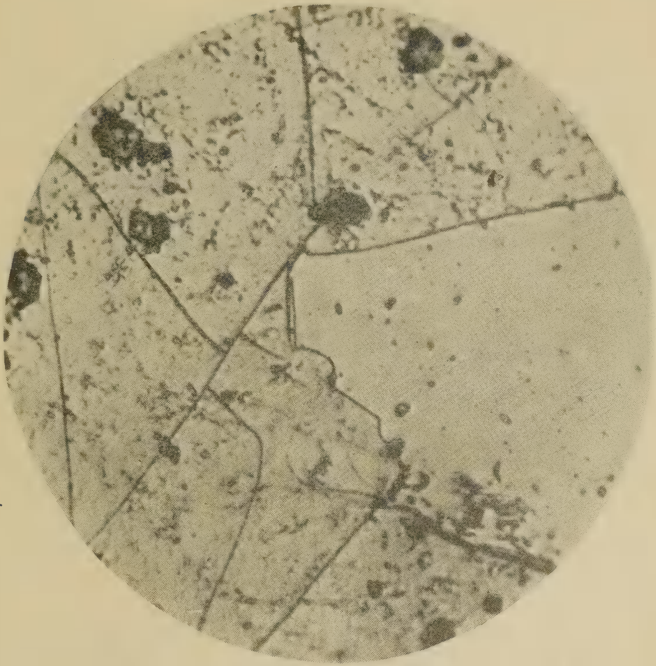

FIG. 7*a*.—Original weathered surface. Mag. × 250.

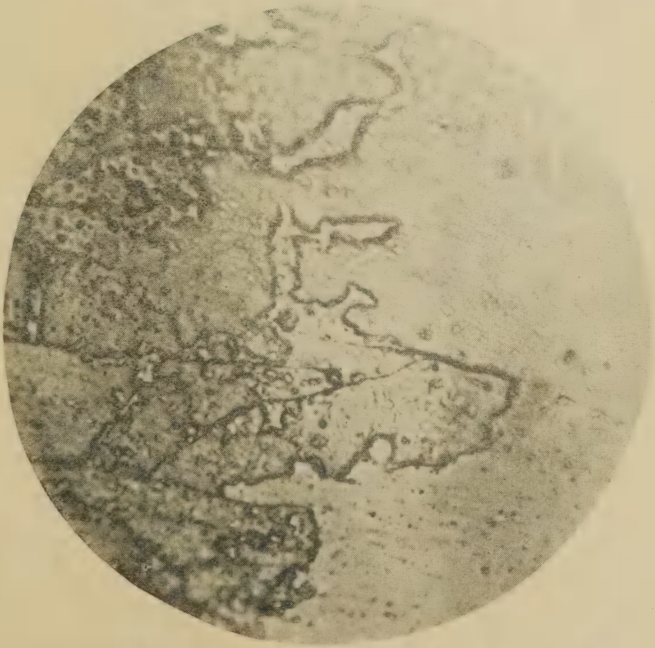

FIG 7*b*.—Weathered surface treated with HF. Mag. × 250.

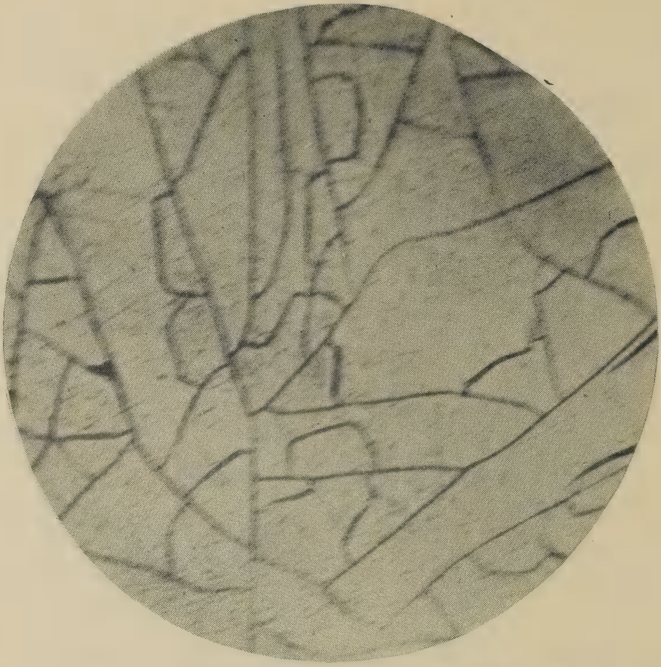

FIG. 7c.—Weathered surface after treatment with HCl. Mag. × 250.

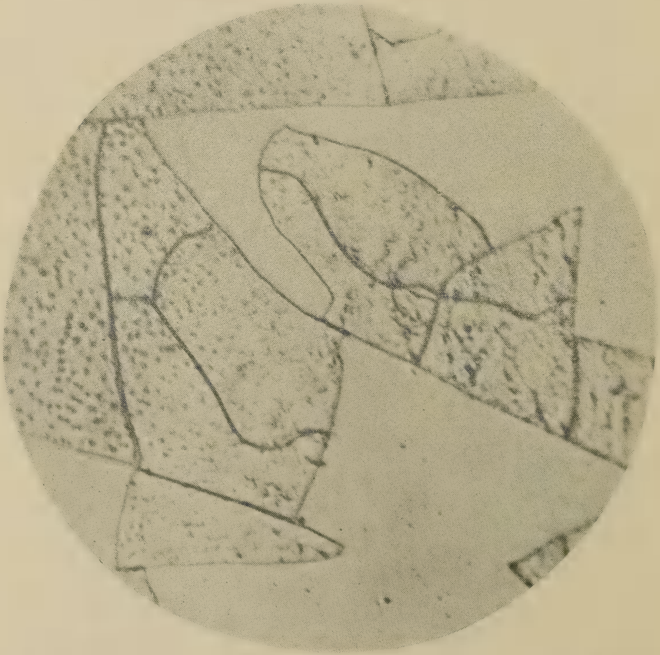

FIG. 7d.—Weathered surface after dipping in boiling water. Mag. × 250.

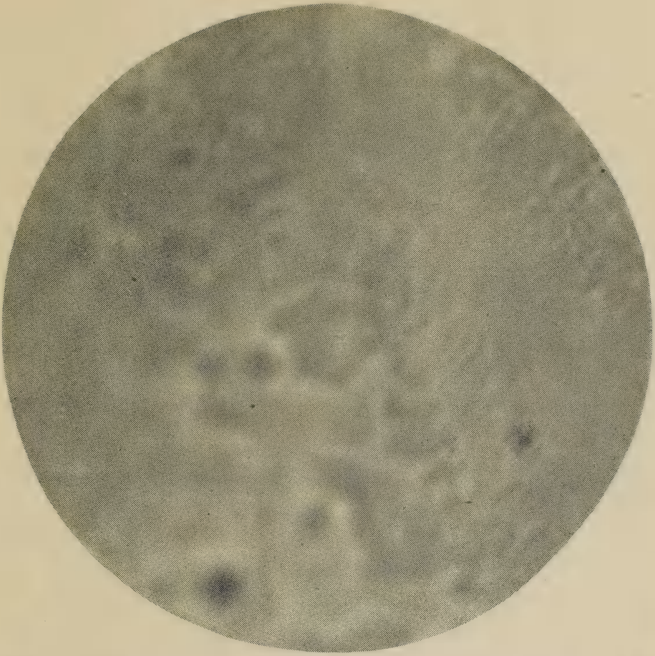

Fig. 7*e*.—Weathered surface after boiling in water for one-half hour. Mag. × 250.

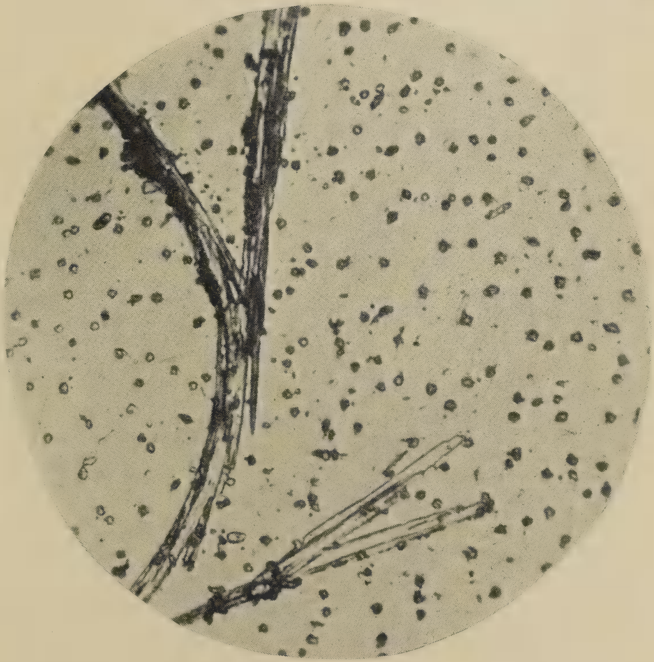

Fig. 8*a*.—Original weathered surface, Class II. Mag. × 250.

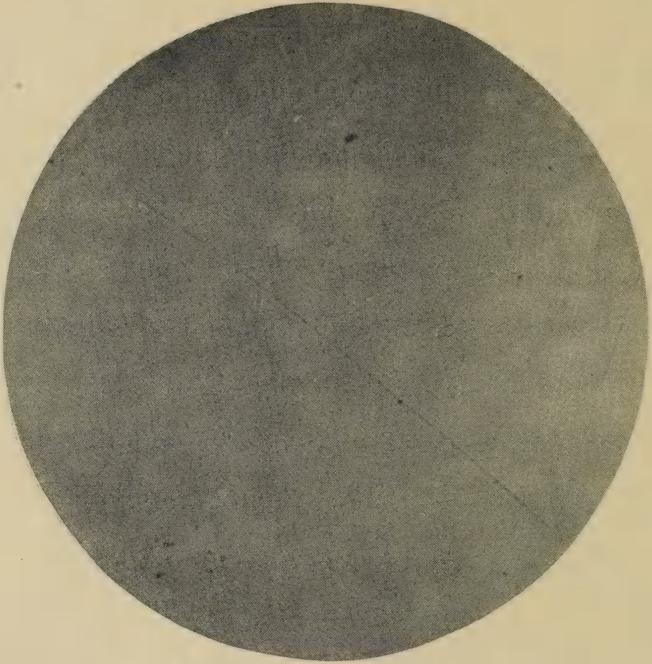

FIG. 8*b*.—Weathered surface after boiling in water for five minutes.

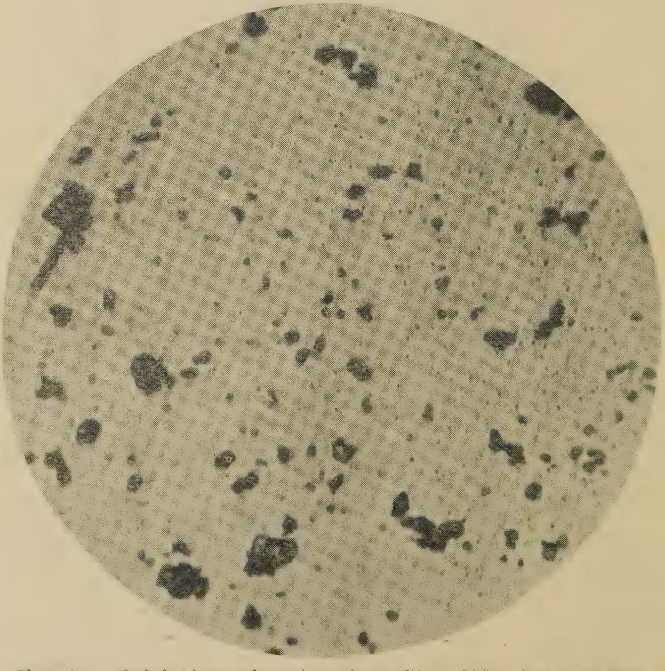

FIG. 9*a*.—Original weathered surface, Class III. Mag. × 250.

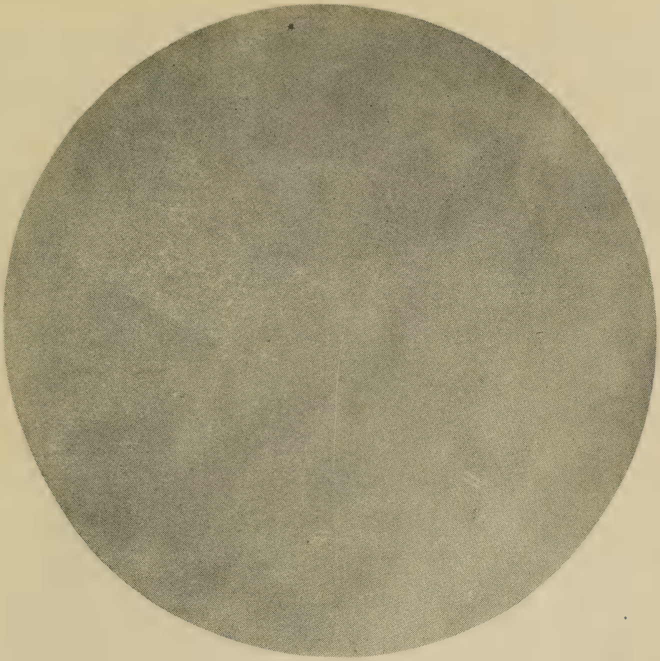

FIG. 9*b*.—Weathered surface after treatment in boiling water for 1 hour. **Mag.** × 250.

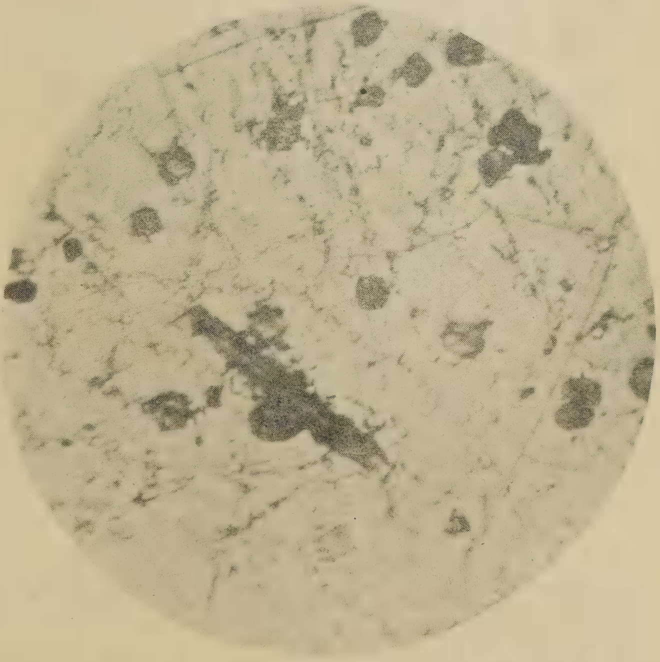

FIG. 10*a*.—Original weathered surface (parallel Nicols). Mag. × 250.

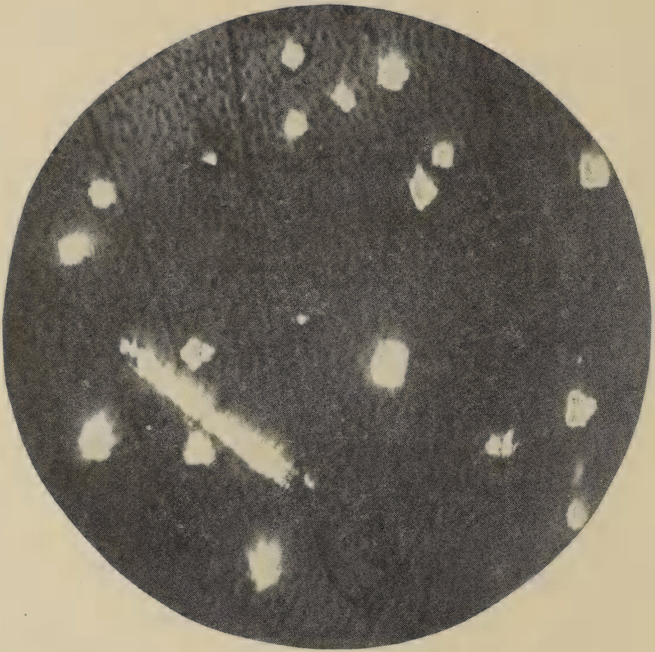

FIG. 10*b*.—Original weathered surface (crossed Nicols). Mag. × 250.

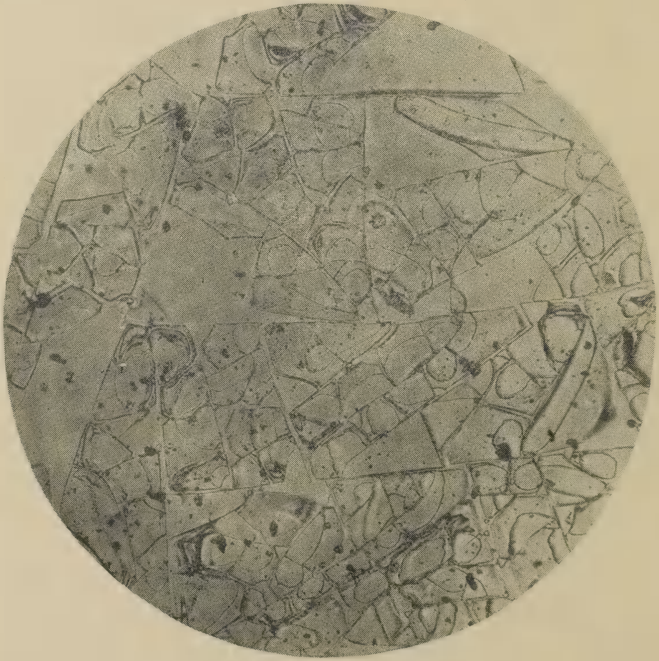

FIG. 11*a*.—Glass containing moisture heated to 350°C. Mag. × 250.

periods in warehouses subject to very wide and frequent changes in atmospheric conditions. The characteristic feature is the heavy white deposit which resembles the deposit obtained by the evaporation of a salt solution. Coal dust, dirt, and other foreign matter are included with the deposit. Fig. 2 shows a very advanced stage of this class of weathering. The film has broken up into small flakes, portions of which have separated from the glass. Crystals deposited by the evaporation of the alkali solution of the glass are evident above the film. Class II (Figs. 3 and 4) consists of needle-like crystals of alkali salts which resemble a web in their formation. No opaque film occurs in this case. Class III (Figs. 5 and 6) is, without doubt, the earlier stage of Class I and is the most common form of weathering found on commercial glassware. Small circular deposits surrounding crystals or dirt particles enable this type to be easily recognized. There is no continuous film on the surface and the weathering appears to be confined to certain areas.

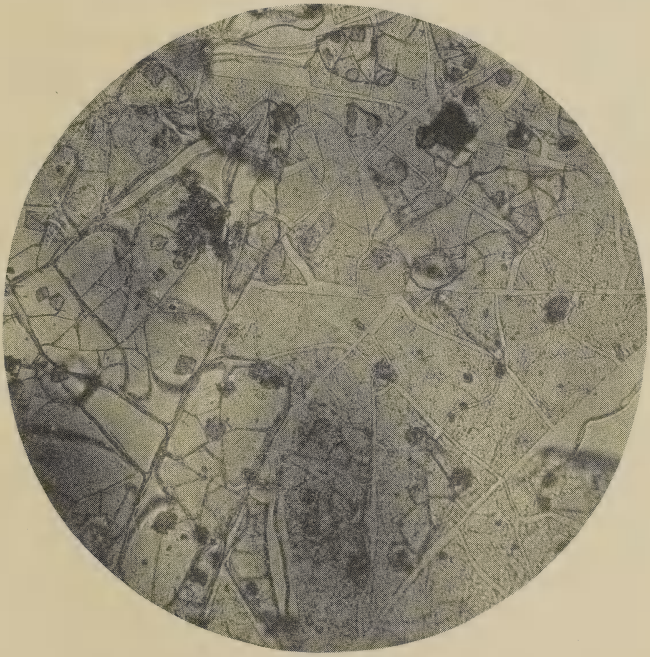

Fig. 11*b*.—Weathered glass heated to 350°C. Mag. × 250.

Effect of Chemicals

A microscopic examination of the effect of a few simple reagents such as might be employed commercially for treating weathered glassware has been carried out and the photomicrographs taken at 250 diameters are presented to illustrate the effects of the different reagents. Fig. 7*a* shows the original weathered surface of a light green beverage bottle, a typical Class I deposit. The bottle was stored in the open but protected from the rain. The outer skin is broken up into segments one of which has separated. Fig. 7*b* illustrates the solvent action of hydrofluoric acid which has attacked the entire film. Hydrochloric acid dissolves the crystals, but does not affect the film, as is shown in Fig. 7*c*. When the glass is dipped in boiling water several times a similar result is obtained. Fig. 7*d* is similar to Fig. 7*c* except that the boiling water has removed several portions of the film. Continued boiling removes the entire deposit giving the clean surface of Fig. 7*e*. The web-like deposit of Class II is easily removed by a few minutes treatment with boiling water. Fig. 8*a* affords a more detailed view of the crystalline formation of the deposit. Five minutes' boiling proved amply sufficient to remove all evidence of the deposit (Fig. 8*b*). A druggist's bottle which had the characteristic weathering of Class III was selected as a third sample. The deposit developed during a few months storage in a well-ventilated modern warehouse. In this case is was necessary to extend the boiling for almost an hour before the surface became entirely clear. Figs. 9*a* and 9*b* show the surface before and after treatment with boiling water.

Products of Weathering

The products of weathering are crystals of a soluble salt and a film of opaque material on the surface of the glass. The crystals exist in different forms and frequently occur when no film or formation of any other material is evident as in Class II. Photomicrographs, Figs. 10*a* and 10*b*, were made with the purpose of showing the crystal formation. This photomicrograph is the same as Fig. 7 except that polarized light was used. The first photograph was made with the Nicol prisms parallel and the result is similar to Fig. 7*a*. When the Nicol prisms were crossed the crystals alone are visible as white areas in the photomicrograph. Chemical analysis has proved these crystals to be principally sodium carbonate. The insoluble film shown in Fig. 2 was removed by brushing and its composition determined by chemical analysis. Different analyses did not check exactly owing to the impossibility of separating the film from all the small particles of glass. The following average of several determinations will give an idea of the composition of this material. The lime, soda, and silica are present in approximately the same proportions as in the glass.

SiO_2	CaO	Na_2O	CO_2	Moisture, organic matter and dirt
66%	7.5%	14%	7.5%	4.0%

Technical literature contains the results of numerous studies of the solubility of glass and its resistance to weathering which are not referred to, the purpose of this paper being to present the information relating to glass containers in such a manner that the apparent causes of weathering will become clear to those interested in commercial glass. Some of the earlier methods used in obtaining results of solubility have been adapted to bottles and similar glass containers to illustrate the mechanism of weathering. The application of many of the results found and theories formulated have so far not been applied to glass containers. The glass manufacturer is interested in the action of atmospheric agents on the original surface of that type of glass common to American practice. The significant feature of this consideration of the problem is that the original surface is retained and any permanent change produced in the outer layer of the glass by the chilling effect of the mold or by the moisture content of the air employed in blowing exerts an influence on the final results obtained.

The generally accepted theory for the weathering of glass assumes that moisture condensing on the surface of the glass dissolves any soluble material. Such material is considered to be principally free alkali. The carbonic acid of the atmosphere reacting with the alkali in solution forms carbonates which crystallize out on evaporation. The action extends beyond this when moisture is absorbed by the glass and some soluble material below the surface is dissolved. When the glass dries this material in solution is deposited on the surface leaving the outer skin porous and marked with solution pits. Whether the moisture dissolves sodium silicate which is similarly affected by the carbonic acid is not certain. The appearance of certain deposits suggests that sodium silicate has been broken up into sodium carbonates and free silica. Boiling experiments carried out at the Bureau in which tumblers were used prove that glass dissolves to give a solution containing silica, lime and soda, although the soda is in considerable excess. At the same time particles of insoluble material resembling silica and insoluble silicates collect in the bottom of the containing vessel.

Solubility and Resistance to Weathering

The term "solubility" is used to express the relative rates at which glass is decomposed by water at definite temperatures and pressures to correspond with the present system of comparing glasses. Glass has no definite solubility in a strict chemical sense. The various reactions with water have a time limit and saturation with *glass* is never attained.

Weathering is largely dependent on the solubility of the glass. The most pronouncedly weathered glass examined has the highest solubility and shows more effect from treatment in the autoclave at 25-pound pressure for six hours.[1] Likewise the glass which was most resistant to weathering

[1] Williams, *Jour. Amer. Ceram. Soc.*, **5**, 508 (1922).

proved to be very resistant to the action of water at pressures and temperatures above normal. The effect of atmospheric conditions on these two glasses differs considerably. An analysis of these gives the following composition:

	SiO_2	R_2O_3	CaO	MgO	Na_2O	MnO
Glass A (the resistant)	76.2	(Al_2O_3–1.12) (Fe_2O_3 .005)	5.27	3.15	13.4	0.82
Glass B (green glass) (the badly weathered sample)	67.4	.80	8.47	.33	22.0	

Another glass of the following composition is typical of American practice. This glass gave a fairly pronounced deposit after several months' storage.

SiO_2	R_2O_3	CaO	MgO	Na_2O
72.15	0.52	7.57	1.01	18.75

The solubility of this glass is much less than that of Glass B and the durability under autoclave treatment is only slightly less than that of Glass A. Yet it has a greater tendency to weather than the first glass. It is evident that the weathering properties are partly dependent on the composition.

If glass, which has been boiled or subjected to water at high pressures and temperatures for a period sufficient to force water into the glass, is then heated fairly rapidly to about 350°C the surface will undergo a breaking up action giving the glass a "fuzzy" appearance. Fig. 11*a* shows the appearance of the surface after the above treatment. This action is accompanied by a loss in weight equal to .02–.05% of the weight of the glass. This appears to be the result of a rapid driving out of the moisture absorbed in the surface of the glass. If a sample of naturally weathered glass is heated in the furnace to 350°C in a similar manner the result shown in Fig. 11*b* is obtained. The two are practically identical in appearance. The surface change produced by heating proves that weathered glass absorbs moisture similar to glass which is subjected to water at high pressures and temperatures.

Chemical Composition of Glasses and Resistance to Weathering

A series of glasses which have been studied in this investigation was arranged in order of their lime to soda molecular ratios. The least ratio was 1 to 1.26. The glass giving this ratio had a silica content nearly equal to the silica content of several other glasses. The solubility, resistance to solvent action of water at temperatures and pressures above normal and the general appearance were slightly superior to those of all other samples. The solubility and tendency to weather increased directly as the lime to soda ratio. The silica content differed slightly, but marked divergence in the two properties mentioned appears to be the result of the increase in soda. A very significant fact was the apparent effect of alumina. Glass with high lime to soda ratio and one per cent of alumina had properties consistent with a much lower lime to soda ratio. An increase in the amount of alumina exerts an influence on certain properties of the glass similar to an increase in lime, but for equal amounts alumina appears to be the more effective. There exists no well-founded theory for the action of alumina as both the acidic and basic properties are considered in the discussion. Frink[1] mentions the tendency of alumina to segregate in the outer skin of the glass. He claims this accumulation of alumina near the surface produces a skin effect which enables the glass to be more easily worked and also increases the resistance to solvent action and weathering. This particular phase will receive further investigation.

Effect of Condition of Surface

Another factor[2] which has considerable bearing on the question of solubility is the condition of the surface. Weathering generally appears on the inner surface, while spalling and chipping produced by treatment in the autoclave is confined to the outer surface. By roughening the inner surface with emery it is possible to obtain spalling on the inside of blown ware. By heating glassware to the plastic point it is possible to prevent spalling on the outer surface. These changes in surface condition resulting in changes in solubility indicate that surface conditions play a part that may be of some consequence. The almost universal occurrence of weathering on the inside suggests the possibility of factors introduced at the time of manufacture or conditions produced by the air used in blowing, which assist the reactions of weathering. This may be simply a surface effect.

The possibility of sodium carbonate existing in the glass after manufacture and thereby increasing the tendency to weather has occasionally been suggested. Determinations made by Masao Ikawa[3] give the amount of sodium carbonate as .021 to .055% but it seems probable that the presence of this salt may have been due to the action of the atmosphere on the ground sample. However, if sodium carbonate could be definitely shown to exist in the glass, near the surface, it would furnish an explanation of the tendency to weather, in short periods, in storage.

[1] *Trans. Amer. Ceram. Soc.*, **15**, 692 (1913).

[2] Williams, *loc. cit.*

[3] *U. Chem. Soc.* (Japan), **42**, 763–85 (1921).

Conclusion

The investigation was confined entirely to soda-lime glassware of American manufacture. The attitude has been analytical. A few conclusions have been drawn regarding the occurrence of weathering on glass of different composition. The general conception is that under the proper conditions any type of commercial glass will weather in storage to a certain extent.

The author wishes to express his gratitude to Mr. A. E. Williams of this Bureau for his many helpful suggestions, and to thank Mr. R. A. Lofton of the Paper Section of the Bureau for his generous assistance in connection with the photomicrographs.

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THE RELATION OF FINENESS OF GRINDING TO OPACITY IN WHITE ENAMELS

By B. T. Sweely and E. S. Prince

ABSTRACT

The problem of securing a uniform opacity by making observations of smelting, testing of raw materials, etc., led to the conclusion that the most important process was the mill treatment given the mixture. A table showing screen analyses of white enamels is given.

The question of opacity is always of interest to manufacturers of white enameled wares, inasmuch as the cost of the enamel is usually dependent upon the opacity of the enamel used. It is almost an axiom that there is no such thing as a cheap white enamel, since the materials which lend opacity, *i. e.*, tin oxide, kryolith, etc., are usually the more costly of the raw materials used, and a given opacity can be secured only by the use of sufficient of these opacifiers to bring about the desired result.

The writers were led to investigate the relation of fineness to opacity, by the difficulty encountered in trying to control the opacity of two-coat ware, that is, ware having a single coat of white enamel applied over a ground. Our problem here was to secure a uniform opacity from piece to piece and from day to day, it being not unusual to experience variations in such ware that would render 40 or 50% of a day's run too dark to be salable, and necessitate redipping, burning, etc. After careful observations of smelting, testing of raw materials and so forth we were forced to the conclusion that the solution of our trouble lay in the mill treatment accorded the mixture used, and we therefore proceeded to make a systematic study of our milling conditions.

The conditions in our factory do not lend themselves readily to the storing or "aging" of the finished enamel. It is, I believe, the practice in some factories to age the enamel for some little time after milling before it is placed in the dipping tubs, thus allowing any excess water that may be present to "settle off." Lack of space at our shop does not permit this, and we are forced to use our enamel either right from the mills, or within twelve to twenty-four hours. Under these conditions it was important that we keep our water content at a minimum in order to secure the proper dipping consistency and therein lay our trouble.

We found in our study that a variation of one-half a cubic foot of water added at the mill in a glass charge of one thousand pounds made a decided difference in the fineness of the finished enamel when milled for a given time. Such a variation in water content was not at all unusual due to the varying lengths of time the glass used had stood or "drained" after smelting. The result was a variation in fineness and consequent opacity when the enamel was applied to the ware.

The reason for such variation is rather obvious. Opacity is essentially a refraction phenomena and if the maximum effect from any opacifier used as a mill addition is to be attained, it is necessary that the opacifier be finely divided and evenly disseminated throughout the coat of enamel in which it is used.

Since the glass itself as used for steel ware is not usually opaque enough to produce a suitable enamel without the use of an opacifier in the mill, it follows that any particle of glass that has as great a diameter as the thickness of the coat applied will have only the opacity of the glass itself, since in this case no refraction of light by the particles of tin or other opacifier can take place. The result will be a grey or spotted coat of enamel.

Obviously, if the above is true on rather coarse particles of glass, the same will be true at any degree of fineness since the more perfectly the particles of glass are separated and surrounded with the opacifying particles, the more perfect will be the refraction of the light falling upon the finished ware and the greater the opacity. For this reason we decided the solution of our problem lay in controlling the fineness of the milled enamel and consequently proceeded to run a number of screen analyses of the enamel as it came from the mills. Below are given data on a number of screen analyses run on the glass during these tests:

TABLE I

SCREEN ANALYSES OF WHITE ENAMELS

No.	60	80	100	120	150	200	H_2O%	Sp. gr.	Mill time
0	0	3.47	5.57	22.35	29.12	50.87	26.5	1.867	20 hrs
1	0	0	.64	12.48	19.12	42.22	28.6	1.827	20 hrs.
2	0	1.18	2.02	16.15	23.21	45.76	28.1	1.833	21 hrs.
3	0	0	0	8.2	14.10	38.50	28.01	1.842	23 hrs.
4	0	0	0	3.81	9.35	31.9	29.2	1.816	22 hrs.
5	0	.34	.65	9.35	15.81	39.91	28.29	1.830	22 hrs.
6	0	0	0	7.94	10.51	32.92	29.70	1.808	21 hrs.
7	0	0	0	6.00	11.27	33.77	29.4	1.815	22 hrs.

The data given is the per cent of glass retained on the respective screens. The water content is expressed in terms of the wet weight of the slip. These tests were all made on samples taken from different runs on the same mill under factory conditions before any attempt was made to standardize the milling beyond weighing the glass and measuring the water.

Of these enamels Nos. 0, 1 and 2 were too coarse to give good opacity on two-coat ware. Nos. 3, 5, 6 and 7 all produced enamels of good opacity, and dipping properties, while No. 4 was very opaque but difficult to dip uniformly. The conclusion drawn from these data was that for this type of ware and under our factory conditions, the best results were to be expected when the glass was milled to a fineness such that all would pass 100-mesh and from 5 to 10% be retained on 120-mesh.

The results of this study we at once put into practice with very good results. We succeeded in eliminating much of the variation in opacity noted above, and have secured more consistent results on all our ware by following the practice of testing for fineness before putting the enamel into use.

It is our opinion that control of the grinding operation on this basis, will largely eliminate the necessity for aging the enamel when it comes from the mill. We have made a number of comparative tests with aged and freshly-milled enamels and have never found any difference in the opacity of the ware, where fineness, specific gravity and water content were the same at the dipping tub. While this may be due in part to the clay used, as compared with that used by others where aging is thought to be beneficial, still it is hard to understand how the opacity of an enamel can be improved by aging in water a number of insoluble ingredients.

In general, it might be said that proper milling is equal in importance to any phase of the enameling process and closer control at this stage of the preparation of the enamel will go far toward the elimination of many of the defects that occur during the application of the enamel to the ware.

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Discussion

Mr. Wells:—I take it that the finer the enamel the more opacity you get. I would like to ask Mr. Prince if there is any limit to the fineness.

Mr. Prince:—We have not gotten to the place we should to determine that point, but we make our determinations on the ground enamel passing a given mesh. We like to get it passing 120-mesh.

Mr. Poste:—Is that sprayed or dipped?

Mr. Prince:—It is dipped. This all applies to dipping. I have not had any experience in other lines, and all I said applied to dipping. The fineness of the enamel always has a great deal to do with its dipping properties. Those of you who have dipped enamel know that if it is coarse you can handle it more easily than you can the finely ground, so the difficulties you run into when it is finely ground will be appreciated by some of you. That is, when you take it directly from the mill and dip it.

Mr. Manson:—I would like to ask if, with the actual weight of dried enamel, from a piece in each case, it would not be possible that you really get more enamel on the piece when it is coarse.

Mr. Prince:—I would say these tests are not laboratory tests. We would run one hundred samples set up in the same consistency by the same individual. The results were conclusive to us.

MANUFACTURE OF SINGLE COAT GRAY ENAMELED WARE[1]

By Howard C. Arnold

ABSTRACT

The manufacture of single coat, mottled gray enameled ware presents a diversity of problems as will be evident from a casual consideration of the following specifications.

1.—The black shape has to be completely covered in one coat as the lack of a second, or cover coat makes it impossible to hide a blemish, scratch or mark.

2.—This coat must have all the gloss, luster and appearance of a finish coat.

3.—It must show two colors, and these colors must be produced from the same enamel and in a single dipping.

4.—The two colors must be present in correct amounts and, at the same time, must be distributed in such a way as to give a pleasing effect.

Preparation of Black Shape

In general, the black shape is prepared in the same way as in the multi-coat process. There appears considerable difference of opinion (and this is shown in varying practice) in the relative value of caustic cleaning and annealing, or scaling. Most of the larger plants making both single and multi-coat ware anneal their black shapes. However, in some of the single coat plants, caustic cleaning is being used entirely.

Sulphur annealing has been used in the past in preparing shapes, according to which the shapes were packed in metal containers, sprinkled with sulphur, sealed and then annealed for 6 or 8 hours at 1000° to 1200°F. Just what this accomplished is hard to say. No doubt the sulphur served to deoxidize the atmosphere and prevent the formation of scale, and the annealing may have assisted in the mottling by removing all strains in the steel, thereby making it more uniformly susceptible to the attack of the mottling reagents. This process, the writer believes, is still in operation in some plants, but in most places has been abandoned. It will, therefore, not be considered further.

The writer's experience with annealing and caustic cleaning has been sufficient for him to make a definite decision between the two. It has led him to the conclusion that when caustic is used, it is not always possible to get every article properly cleaned. Pieces made from rusted steel, or which have been subjected to severe spinning or drawing action, usually give trouble, while fabricated shapes, and shapes which have been subjected to only slight drawing, are cleaned quite successfully. In general, caustic cleaning is about 80% as reliable as acid dipping and scaling, (or annealing).

In cleaning we have used caustic soda, sodium carbonate, trisodium phosphate and silicate of soda mixed in various proportions. In all cases, an approximately 8% solution of these mixtures is used for the cleaning. The articles are boiled from two to three hours. They are tested for grease by the man in charge, who notes whether the film of water breaks as it runs off the piece. The shapes are then boiled a second time in water in order to remove all adhering caustic before they are placed in the pickling tanks.

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[1] Contribution from the Laboratory of Arthur D. Little, Inc., Cambridge, Mass.

Pickling practice in single coat gray is practically the same as in multi-coat ware. Four to eight per cent hot sulphuric, or cold hydrochloric, acid is used. In connection with hot sulphuric acid pickling, it is quite common to use a so-called inhibiter, the function of the inhibiter being primarily to minimize disagreeable fumes. The ware is pickled fifteen to forty-five minutes, it is then washed, and finally neutralized in a weak soda ash bath. From the neutralizing bath it goes to the dryers, with the exception of some plants practicing "wet-dipping" where it is retained moist as will be explained later.

Enamel Formulas and Preparation

Several volumes could be written on this topic alone. The pros and cons of the various ingredients which make the batch formula have furnished a topic of discussion for years past, and, as far as we can see today, will continue to do so for years to come. The difficulties involved in controlling all variables but one, in determining the effect of various ingredients on the finished article, are well nigh insurmountable. Of course, we can get directions, but to get quantitative measurements is practically impossible. It is beyond the scope of this paper to enter upon such a discussion; the commercially accepted formulas alone will be considered.

With one exception, the clay, the ingredients used in single coat gray ware are the same as those in multi-coat. As the clay functions as the opacifier, as well as the suspending medium, it has to have additional properties. In the writer's experience, the ordinary plastic ball clays, such as are used in multi-coat ware, when applied to single coat gray, do not give the proper finish. Either they burn too dark or produce a rough surface with no gloss. Usually the fat clay merely dissolves in the enamel frit, leaving the coating black. The clay must have the power of floating the enamel frit, or "set up," and, at the same time, it must resist the fluxing action of the glass during burning. What is required can best be described as a plastic kaolin, or china clay. Fortunately, the gray color makes it possible to use other than white burning clays; even those stained considerably with iron are satisfactory. To realize the best conditions, a blend of clays can be used such as a refractory plastic with a ball clay.

Another method for producing opacity is the use of an opacifier with a clay which will dissolve in the frit when the piece is burnt. Various substances have been tried, such as tin oxide, antimony oxide, magnesium spinel, aluminum hydroxide, titanium oxide, zirconium oxide, fine ground diaspore, etc. With these ingredients, however, we strike the following difficulty. Clay, when subjected to the action of mottling salts, is dissolved or fluxed in the area of the mottle and left unattacked outside. The opacifiers mentioned above seem to resist the mottling salts, and, instead of getting the dark areas necessary to produce contrast in the light and dark of the enamel, we get only a faint darkening in the mottled areas, which at a distance gives the impression of a solid color. Besides the above objection, in the case of tin and antimony oxide, there is a further one, a reducing action of the sheet steel on the oxides to form the lower oxides with an accompanying discoloring and blistering. Zirconium oxide is not affected by the steel, and, in its basic silicate form, gives better results than any of the other compounds. The same bleaching effect on the mottle is produced from cryolite, or any combination of aluminum and fluorine in the frit, although not to the same extent as in the case of a solid opacifier.

Various single coat formulas have been published, and the writer ventures to say that, in the ratio of refractories to fluxes (this being the fundamental proportion which must be correct) 90% of the formulas in production today do not vary 15% from those published. Of course, there are a great many ways in which there can be a variation in adding the refractories and fluxes, but the fundamental condition is fulfilled. Danielson[1] has published formulas which may be taken as typical. Our best results have been obtained with a high feldspar, low quartz and fluorspar mixture. The refractories and fluxes are balanced accordingly.

Here again, the single coat enamel is subject to a great many troubles not found on multi-coat. For instance, we have a phenomenon called depressed mottling. That part of the surface where the mottling salts are concentrated will burn to a thinner coating than the other part, and, as a consequence, will form a depression on the surface. If we decrease the calcium oxide, we encounter this trouble. Cryolite, in small amounts, is beneficial in producing opacity, but, as explained above, its use is limited. Furthermore, opacity obtained with cryolite produces a less substantial, more soluble enamel than when it is produced with clay. We have obtained good results with the following formulas:

Feldspar	33.50	48.0	38.0
Sodium carbonate	12.50	3.0	4.5
Sodium nitrate	3.75	3.0	4.5
Borax	24.50	29.0	28.0
Fluorspar	6.75	4.0	5.0
Quartz	15.00	...	12.0
Oxide antimony	1.50	2.0	2.0
Cryolite	3.25	3.5	4.0
Bone ash	3.75	3.0	...

The influence of other factors in production is far greater than that of formulas, and, unless these other factors are properly balanced, the best formula ever written will not make good enamelware.

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[1] R. R. Danielson, "A Classification of Enamels for Sheet Steel," *Jour. Amer. Ceram. Soc.*, **3**, 961 (1920).

Making the Batch

The raw batch is fritted in a rotary smelter which is fired with oil. Batches of 450 pounds are smelted at one time, taking from 1.5 to 2 hours per smelt. The frit is quenched in the usual way, then dried and stored.

The making of the enamel from the frit will depend upon the method of dipping. There are two methods in use:

1. Wet dipping method, in which the mottling agent (usually a weak solution of H_2SO_4) is on the black shape.
2. Dry dipping method in which the mottling solution is added in the enamel.

In the first method, the wet dipping, the black shapes are either brought directly from the pickling room without drying, in which case they still retain a small amount of acid from the pickling vats, or the pieces are dried in the pickling room in the usual way, and then immersed in a weak acid solution just before dipping.

In the second case, a mottling salt is added to the enamel, either on the mill, if the enamel is to be used immediately, or just before dipping. The effect of these salts is dissipated upon standing. Various salts can be used. Among those most common are cobalt sulphate, nickel sulphate, and ferrous sulphate.

The frit, with 5 to 7% clay and 50% water, is ground in a ball mill to pass 80-mesh screen. Fifteen minutes before a mill is finished, 1/2% magnesium sulphate is added. The enamel is then ready to use. We let it age for three or four days, although the writer cannot say definitely that this aging has any beneficial effect.

Dipping

In the wet process, care must be taken that the water content does not become too high. As each piece dipped carries with it a certain amount of water, and leaves it in the dipping tub, it is necessary to add, from time to time, a certain amount of thick enamel. This may be done at the discretion of the dipper, or under the direction of the forelady.

In dry dipping, there is little variation from standard practice. The pieces are not shaken so hard as they are in ground coat; the layer of green enamel is much thicker. Just before dipping in the enamel from 1/2 to 3/4% of mottling salt in solution is added. Because of the thick coating desired, the resultant thickening of the enamel is not disadvantageous.

Mottling and Drying

The mottling or corroding reaction from a chemical point of view is very complicated. It is controlled by the following conditions:

1. The purity of the iron.

2. The distribution and size of particles of the impurities in the iron (structure).
3. The degree of alkalinity or hydroxyl-ion concentration of the enamel.
4. The degree of oxidation of the iron salts formed in the reaction.

The rusting is due to a difference in electric potential between electro positive and electro negative areas, on the surface of the iron. The electrically opposed areas are formed from the impurities in the iron, and they, as well as the potential difference between them, will vary with the kind of impurity and its distribution or grain size.

With a given steel surface, the extent of the running of the mottle, or the control of its character, is regulated by the alkalinity of the enamel and the extent of oxidation of the iron salts formed. The three mottling salts mentioned are all salts whose bases are insoluble. When they have been in contact with the alkaline sodium silicate or hydrate (which can be present in very small amounts only) the sodium ion will unite with the sulphate ion and the cobalt or nickel will be precipitated as the insoluble hydroxide.

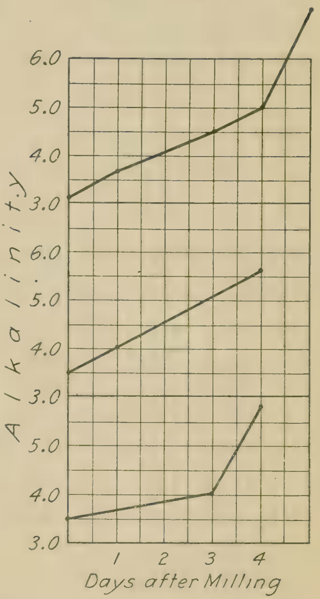
It is the acid nature of these cobalt, nickel or iron salts which momentarily furnishes a negative ion that produces the mottling. If the salt has been standing in the enamel too long, or if the enamel has too high a hydroxyl concentration, the above reaction will have been completed and the salt will have lost its mottling effect. Then, in place of connected runny mottling, we will have a series of dark spots, each with a high concentration of ferrous salts. In fact, the concentration becomes so great at times that red oxide of iron is formed on burning and leaves red spots.

The condition of oxidation or reduction in the enamel, as has been stated above, is of effect in determining the character of the mottle. The reason for this is as follows: When the iron sulphate formed by the corrosive action of the enamel on the metal succumbs to the hydroxyl ion and is precipitated, it will precipitate as one of two compounds, ferrous hydroxide or ferric hydroxide. The ability of ferrous hydroxide to form colloidal suspensions, and thus to diffuse farther after its formation than the ferric hydroxide, makes it give better mottling effects. This can be easily shown by experimenting with a highly alkaline enamel, with and without a strongly reducing agent. The spots with red centers will develop immediately in the first experiment, while the dark mottled area will run in streaks all over the piece in the second. There is, of course, a limit in the selection of reducing agents. Organic reducing agents will blister and blow when the piece is burned. Sodium thiosulphate gives good results; cobalt and nickel salts also function as reducing agents.

In the wet dipping method the chemical control of the enamel is not necessary. The mottling agent (weak sulphuric acid) does not touch the enamel until the enamel is in contact with the steel. In this way it has the maximum length of time to react before the ferrous sulphate is precipitated as hydroxide. Furthermore, there is no insoluble base to be precipitated. Even here, in the writer's opinion a small amount of reducing agent would be advantageous.

The wet process is very reliable, not so susceptible to external influences, and can be depended upon to run constantly. The dry dipping process must be controlled more carefully. As stated before, the alkalinity or hydroxyl-ion concentration is very important. This can be determined by titration of the water in the enamel, and corrected by addition of acid. However, it is much better to have the enamel at its correct alkalinity.

The alkalinity is dependent upon many conditions, the more important being (1) the ability of the frit to resist the action of water in the enamel, (2) the age of the enamel. It is, accordingly, best to use the enamel before the alkalinity has developed beyond the maximum point allowable as shown by experience. On the other hand, over-correction with acid, or an enamel with too low an alkalinity, gives no mottle at all. That is, a dark color will cover the whole piece and there will be no light areas to produce contrast. The color produced is not so dark as that produced with the proper alkalinity. Here the correction is made by blending in old enamel of high alkalinity. The curves in Fig. 1 show the increase in alkalinity of an enamel with increase in age. These were taken from actual enamel batches waiting to be used.



Ordinate - An arbitrary unit of comparison only

FIG. 1.

The time required for developing the mottle is from two to two and one-half hours. In order that the proper reaction be produced, the piece must be kept moist, just as it comes from the dipper, for this length of time. There are two methods of obtaining this result: (1) Regulate your temperature and humidity conditions so that the piece is almost dry when the mottling is completed and it is a matter of only a few minutes for it to become completely dry, or (2) keep the temperature of the mottling normal and pass the completely mottled piece through a rapid dryer, where it can be dried quickly. If the ware is dried too slowly, or remains in the moist condition too long after mottling is completed, we may get too high a concentration of iron salts, and then, on burning, these salts will not be taken up by the frit, but will give off gases and produce small black spots or pinholes.

The process of drying, with the exception of the mottling phase, is the same as for multi-coat. The ware is placed on trucks from the dippers, left in the mottling room and either dried completely in the mottling room, or passed from there to a rapid dryer. In some plants, steam racks are used instead of kilns. The amount of steam and the temperature of the racks will be regulated according to external conditions; in hot weather it is not necessary to use any steam, while in cold weather, when the air has low evaporating power, steam is required.

Burning

Burning presents no problems not met with in multi-coat ware. We have the same problems of capacity and type of furnace, kind of fuel, style of fork and number of operators on a fork. We have used the fire-clay muffle furnace, coal fired, and the carborundum muffle, oil fired. The carborundum muffle is very elastic; it can be heated to full burning temperature, 1550–1600° in 4 to 6 hours. Temperature changes can be made rapidly; in case of a Sunday shutdown, or where the furnace has not cooled completely, it can be brought to heat in 3 hours. Electric furnaces and direct fired oil furnaces, both without muffles, are new developments in this field.

We have our share of trouble from overburning and underburning. Overburning kills the gloss and burns the edges dark. When the ware is greatly overburned, it volatilizes the enamel, turns the ware black, and exposes the steel surface.

Underburning leaves blisters and fine pinholes although the gloss is usually good.

Fishscale

No paper on enamelware would be complete without some mention of this problem. We have periodically a certain amount of fishscale. It would extend this paper to too great a length to present a discussion of its causes and control. In single coat gray ware, fishscale is encountered much more than in multi-coat ware. The mottling process, the variation in chemical nature between light and dark areas, and the strains that are thereby introduced, make this enamel more susceptible to fishscale than multi-coat. The necessity of burning one coat to a gloss is also a contributing factor. Fishscale, to a certain extent, is independent of the batch formula. No amount of variation in the formula is entirely sufficient in itself to eliminate scale.

In conclusion the writer wishes to acknowledge his indebtedness to Crunden Martin Manufacturing Company, St. Louis, Missouri, where his experience in this field has been acquired as a representative of Arthur D. Little, Inc., 30 Charles River Road, Cambridge, Massachusetts.

CHROME REFRACTORIES[1]

By J. Spotts McDowell and H. S. Robertson

ABSTRACT

A compilation from the available literature is presented, giving the more important data on chromite and chrome refractories. A bibliography is included.

Introduction

The high refractoriness and neutral chemical character of chrome give it an important rôle as a refractory in various types of metallurgical furnaces. However, comparatively little study has been given to its refractory qualities and the literature upon the subject is surprisingly scant. What little there is, is scattered throughout the technical press, and is not readily available. The authors have endeavored to bring this scattered information together, and to supplement it by certain additional data from the laboratory of the Harbison-Walker Refractories Co.

If the properties of chrome ore were thoroughly understood, its use as a refractory material would doubtless be greater. Producers, consumers and investigators should realize that the commercial term chrome ore embraces a group of materials of different chemical and physical properties. Realization of this fact may prevent misinterpretation of results, and make possible the more intelligent use of chrome refractories. The authors hope that the presentation of the data here compiled will lead to further research upon this valuable refractory material.

Historical Note

The first recorded experiments with chrome ore as a refractory were made in the open-hearth furnaces at Terre-Noire, France, in 1879.[2] It was used on a larger scale in the following year at the Alexandrowsky Steel Plant, St. Petersburg. The first recorded use of chrome brick was in England, in the year 1886.

At the Alexandrowsky plant, the hearths of the basic open-hearth furnaces were made of calcined dolomite and other parts of silica brick. A six-inch layer of crushed chrome ore mixed with tar separated the dolomite from the silica. The dolomite for the hearths was calcined in a shaft kiln lined with lumps of chrome ore. These lumps were bonded together with a mixture of two parts by volume of chrome ore fines and one part of lime. By 1886 chrome ore had been adopted at several European open-hearth plants as a lining material for the walls and hearths. These were constructed of blocks of ore laid in a mortar of chrome ore fines, to which lime

[1] Received October 20, 1922.

[2] Ferd. Gautier, "On a Neutral Lining for Metallurgical Furnaces," *Jour. Iron Steel Inst.*, **28**, 151 (1886); *Stahl u. Eisen*, **6**, 504 (1886).

[3] O. T. Tellander, "The Basic Open Hearth Process at the Alexandrowsky Plant, St. Petersburg," *Stahl u. Eisen*, **2**, 599 (1882); *Jour. Iron Steel Inst.*, **22**, 465 (1883).

had been added to cause setting. The hearths were 8 to 10 inches thick. A mixture of the ore and tar was used to fill the tapping holes.[1]

For several years prior to 1886 chrome ore had been used in the basic converters at Eston, England. The bottom walls were lined with dressed blocks of the ore, and dolomite was rammed around the blocks. These linings were said to have given good service.[2]

About 1886 Riley made chrome brick bonded with tar and a small amount of fluxing material. From his description it appears that the brick were not burned before use.[3]

In the late eighties chrome ore as a hearth material for open-hearth furnaces was supplanted by magnesite, which was found to be much more satisfactory. By 1890 chrome was no longer used for this purpose in Russia or Germany,[3] although it was used in France in minor degree as late as 1895.[4]

The use of chrome ore as a refractory in the United States began about 1896. It was employed in the brick form mainly as a neutral course between silica and magnesia brick, and in the ground condition for patching and daubing in open-hearth furnaces. Only a few companies in the United States have ever manufactured chrome brick.

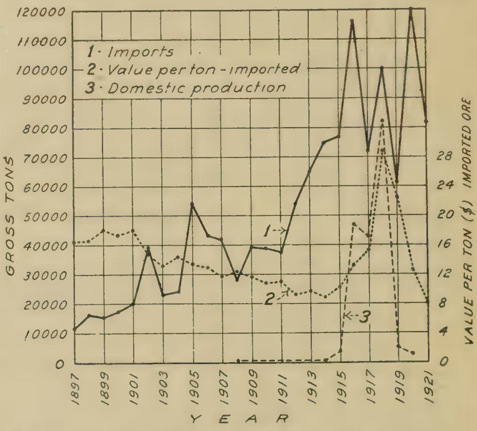


FIG. 1.—Annual consumption of chrome ore in United States.

For many years prior to the war, all but a very small portion of the chrome ore used in this country was imported, mainly from New Caledonia, Greece, Turkey and South Africa. From 1905 to 1914 the average consumption of chrome ore in the United States was about 45,000 tons for metallurgical, chemical and refractory purposes combined. About 35% was used for the manufacture of ferro-chrome, 35% for chemicals, chiefly bichromates, and 30% for refractories and other purposes.[5]

[1] "Chrome Ore as a Furnace Lining," *Stahl u. Eisen*, **7**, 27 (1887).

[2] Ferd. Gautier, *loc. cit.*

[3] "Chrome Iron Ore Linings in Open-hearth Furnaces," *Jour. Iron Steel Inst.*, **34**, 340 (1889); "Chrome Iron Ore Linings," *ibid.*, **36**, 217 (1890); Dr. Leo, "Chrome and Magnesite Brick," *Stahl u. Eisen*, **11**, 643 (1891); *Jour. Iron Steel Inst.*, **40**, 165 (1891).

[4] P. Speier, "Chrome Ore Furnace Lining," *Echo des Mines*, **21**, 584 (1895); *Jour. Iron Steel Inst.*, **48**, 506 (1895).

[5] J. S. Diller, "Chromite in 1918," *Mineral Resources of the U. S.*, **35** [1], 657 (1918).

During the war period there was an unprecedented demand for chrome ore, and prices became so high that California and Oregon ore could be shipped to the Eastern market at a profit, notwithstanding the expense of transportation. Imports reached a high figure. Nearly all of the ore, however, was needed in the metallurgical and chemical industries, and the manufacturers of refractories obtained only a limited amount. At the end of the war, prices again dropped, and little or no chrome ore is now being mined in this country.

TABLE I[1]

CRUDE CHROMITE IMPORTED TO THE UNITED STATES AND SHIPPED FROM MINES IN THE UNITED STATES[2]

Quantities in Long Tons

	1913	1914	1915	1916	1917	1918	1919	1920	1921
Australia	....	....	....	2986	....	15976	13161	2778	....
Brazil	....	....	....	....	....	17854	4800	3451	....
Brit. South Africa	....	....	22800	23000	4750	521	29	39400	23318
Canada	....	533	10087	12200	19012	20949	8941	8491	7554
Cuba	....	....	....	34	17	8821	14461	710	600
French Oceania	21850	30860	28031	30950	10300	25761	7125	56682	35108
Greece	4600	8155	4305	7900	....	....	....	5302	8104
Portuguese Africa	30001	23200	11230	38850	37800	8000	4000	11000	....
Asiatic Turkey	8650	11880	....	....	....	....	3500	12760	5822
All others	79	58	2	5	184	2260	4387	9701	1330
Total	65180	74686	76455	115925	72063	100142	60404	150275	81836
Domestic Sales	255	591	3281	47035	43725	82430	5079	2502	....
Apparent Consump.	65435	75277	79736	162960	115788	182572	65483	152777	....

Mineralogy

The most common mineral containing chromium, and the only one of economic importance, is the oxide, chromite ($FeO.Cr_2O_3$). Other not uncommon minerals containing chromium are picotite (chrome spinel), crocoisite (lead chromate), chrome diopside, chrome garnet and chrome mica.

Chromite is a member of the spinel group of minerals, which crystallize in the isometric system, and which have the general chemical formula $RO.R_2O_3$. Some of the members of this group are:

Chromite	$FeO.Cr_2O_3$
Spinel	$MgO.Al_2O_3$
Picotite	$(Mg,Fe)O.(Al,Fe,Cr)_2O_3$. Contains up to 10% Cr_2O_3
Magnetite	$FeO.Fe_2O_3$
Magnesio ferrite	$MgO.Fe_2O_3$

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[1] See Figure 1

[2] From publications of the United States Geological Survey

Theoretically chromite should contain 67.9% Cr_2O_3 and 32.1% FeO. However, even the purest specimens free from gangue rarely contain over 60% Cr_2O_3 and ores containing 35% or less are common.[1] The diversity of composition may be explained by the fact that chrome ore is really an isomorphous mixture of various minerals of the spinel group in varying proportions, in which FeO may be replaced in part by MgO, and Cr_2O_3 by Al_2O_3 and Fe_2O_3. Such isomorphous mixtures cannot be brought to a higher grade by any mechanical process of concentration. Certain ores contain as much as 11% to 17% MgO, and 20% to 26% Al_2O_3, and hence include in their composition a considerable proportion of the normal spinel molecule.

An interesting study of the molecular composition of Maryland chrome sands has been made by J. T. Singewald, Jr.[2] Two samples of the chrome sand gave the following results after separation into magnetic and non-magnetic portions:

		Per cent of	Molecular percentages			
		Total	$MgO.Al_2O_3$	$FeO.Al_2O_3$	$FeO.Cr_2O_3$	$FeO.Fe_2O_3(Fe_3O_4)$
Sample A	Magnetic	56.5	16	4	31	49
	Non-magnetic	43.5	19	20	52	9
Sample B	Magnetic	5.9	0	8	3	89
	Non-magnetic	94.1	19	45	10	26

The gangue minerals which most frequently occur in chrome ore are olivine, talc, chlorite, and serpentine. Fissures of magnesite, or silica in the forms of quartz, chalcedony or opal are not uncommon. A considerable proportion of the gangue minerals can often be removed from chromite by suitable processes of concentration.

Physical Properties

Chromite is opaque, brownish black to iron-black, with a dark brown to grayish brown streak, and a metallic or submetallic luster. It has a hardness of 5.5 and a specific gravity of 4.3% to 4.5%, being lighter than magnetite, which has a specific gravity of 5.17 to 5.18. It has no cleavage, is brittle, has uneven fracture, and sometimes is feebly magnetic.

Chromite crystallizes in the isometric system, usually in octahedrons. The crystals, however, are generally of microscopic size, and the ores have a massive appearance, being either granular or compact. The melting point of a chromite ore, the analysis of which is not stated, is given by Kanolt as 2180 °C.[3]

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[1] Knopf and Lewis, "Chrome Ores in Maryland, Pennsylvania and North Carolina," U. S. Geol. Surv., *Bull.* **725B,** 117 (1921).

[2] Joseph T. Singewald, Jr., "Maryland Chrome Sand Ore," *Econ. Geol.*, **14,** 189 (1919); *Chem. Abs.*, **13,** 1692 (1919).

[3] C. W. Kanolt, "Melting Points of Firebrick," U. S. Bur. Standards, *Tech. Paper* **10,** 15(1912); *Jour. Gas Lighting,* **119,** 503 (1913); *Jour. Franklin Inst.,* **174,** 225 (1912); *Trans. Amer. Electrochem. Soc.,* **22,** 95 (1912).

Chrome ores are variable in appearance, and the quality cannot safely be judged by visual examination. California ores containing 50% to 55% Cr_2O_3 are usually fine-grained and brittle, resembling anthracite; 40% to 44% ores have the appearance of dull graphite; 35% ores often have a rusty color.[1] However, certain heavy black ores which appear to the eye to be of excellent quality, are low in Cr_2O_3 and contain considerable magnetite. On the other hand good ore may sometimes be thought high in silica, if, as sometimes happens, it is coated with a film of $MgCO_3$ which gives it a white appearance.

Singewald[2] has pointed out that field determinations based upon the magnetic properties of chromites may lead to error. A non-magnetic mineral resembling chrome ore in the field, may be a black spinel, with a comparatively low percentage of Cr_2O_3; while a strongly magnetic mineral may be chrome ore of fair grade, but with an appreciable amount of Fe_3O_4.

Chemical Properties

Of all the common refractories, chromite is the most nearly neutral in its chemical behavior. It is acted upon, however, by either strong acids or by strong bases, being less resistant to the latter than to strong acids.

Chromite is decomposed by fusion with potassium and sodium bisulphate. In an oxidizing atmosphere it is attacked at high temperatures by potash, soda or lime, with the formation of chromates and dichromates. By being mixed with soda and silica it can be fused even without an oxidizing agent. At high temperatures carbon has a reducing effect upon chromite forming an alloy of Fe, Cr and C known as ferro-chrome.

The fusibility curve has been determined for mixtures of Zettlitz kaolin and chrome ore.[3] The ore used contained 52.9% Cr_2O_3, 22.6 FeO, 4.8 Al_2O_3, 9.6 SiO_2 and 10.0% MgO, and had a melting point of about 2000 °C. The melting point of the mixtures decreased rapidly until a eutectic was reached at about 1435 °C for 35% kaolin. Above this the curve rose again to the melting point of kaolin, with another irregularity at 70% kaolin. (See Fig. 2.)

Occurrence

Chromite deposits are found chiefly in basic igneous rocks, peridotite and the serpentine derived from it. To a minor extent chromite occurs in residual clays, and in beach and stream sands, which have resulted from the concentration of particles derived from the weathering of serpentine.

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[1] Harold French, "Manufacture of Chromates from Chromite," *Min. Sci. Press*, **113**, 845 (1916); *Chem. Abs.*, **11**, 385 (1917).

[2] Joseph T. Singewald, Jr., *ibid.*

[3] M. Simonis, "The Use of Chromite as a Refractory Material," *Stahl u. Eisen*, **28**, 334 (1908); *Eng. Min. Jour.*, **59**, 154 (1919); *Chem. Abs.*, **2**, 1685 (1908).

In the primary deposits it does not occur in well-defined veins, but is found in lenticular bodies, usually much longer than broad; in irregular masses or pockets which seem to have no relation to each other, or in stringers and disseminated grains. The ore bodies vary in size from small nodules to masses containing many thousand tons.[1] The largest body mined within recent years in the United States was the Castle Crag Mine in Shasta Co., California; it was 150 feet long, 40 feet wide, 54 feet deep and produced 12,000 tons of commercial ore. It is estimated that the average chromite

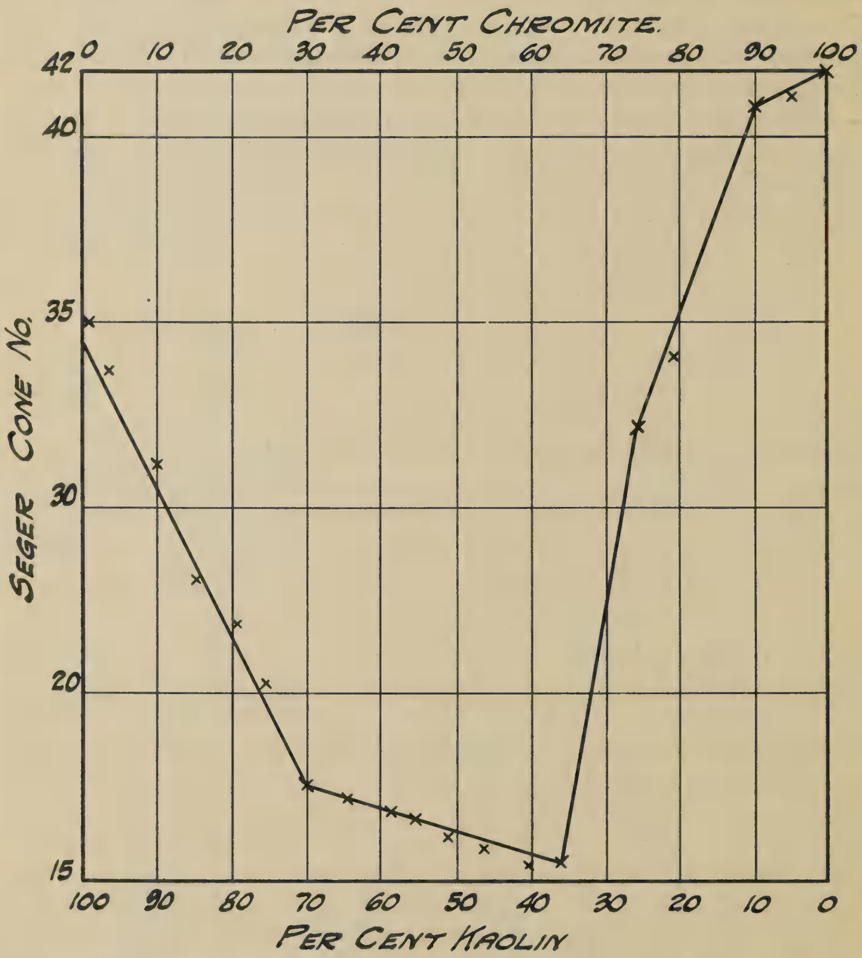

FIG. 2.—The fusion points of mixtures of chromite and kaolin.[2]

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[1] Diller, Westgate and Pardee, "Deposits of Chromite in California, Oregon, Washington and Montana," U. S. Geol. Surv., *Bull.* **725A,** 10 (1921).

[2] *Trans. Amer. Inst. Mining Eng.*, **59,** 154 (1918).

content of the ore-bodies mined in California and Oregon during the war was about 50 tons. These bodies are very small compared with the deposits of New Caledonia and Rhodesia.

Chromite is regarded as one of the primary constituents of igneous magmas rich in iron and magnesia; the ore-bodies were formed through segregation during cooling and consolidation of the molten mass. It is believed that the chromite was one of the first minerals to separate out when the mass began to cool. The longer it remained in solution the less opportunity there was for the formation of distinct bodies, for as the magma began to lose its fluidity the chromite separated out into smaller bunches or in grains scattered throughout the enclosing rock.[1]

Chrome ore liberated by rock weathering and decay may be found at the surface, hence scattered surface boulders are not necessarily an indication of the existence of an ore-body below.[2] On account of the pockety nature of the deposits, mining is subject to great uncertainty and risk. As a rule, no estimate can be made of the amount of chrome in a deposit beyond what is actually proved.

Waste rock may be removed from chrome ore by hand-cobbing, and by mechanical concentration. In the latter case, the ore may be crushed, treated in classifiers and fed to concentrating tables.

Deposits and Production

Chromite deposits occur in many parts of the world, notably Rhodesia, New Caledonia, Turkey, India, Greece, Canada, Cuba and Brazil. In the United States chrome occurs in California, Oregon, Wyoming, Alaska, North Carolina, Maryland and Pennsylvania.

From 1827 until the beginning of the Civil War, most of the world's supply of chrome came from the Baltimore area, Maryland, and Lancaster Co., Pennsylvania.[3] The Wood mine, in Lancaster Co., was an operation in a deposit of remarkable size. It was opened in 1828 and operated for nearly 50 years, producing about 95,000 tons of ore. The ore body had a maximum length of 300 feet and a depth of about 720 feet; its width averaged 20 feet. Chrome mining in this region ceased at some time in the late seventies or early eighties, due to the development of the Turkish deposits.

From about 1880 to 1900 large quantities of chrome were mined from the deposits of Brusa, Asiatic Turkey, which began operations in 1877.

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[1] H. Ries, "Chromium, Its Occurrence and Mining," *Eng. Min. Jour.*, **104,** 988 (1917); Waldemar Lindgren, "Mineral Deposits," McGraw-Hill Book Co., Publ. New York (1913).

[2] Knopf and Lewis, *loc. cit.*

[3] Wm. Glenn, "Chrome in the Southern Appalachian Region," *Trans. Am. Inst. Mining Eng.*, **25,** 481 (1895).

These deposits were noted for their size and cheapness of mining. At the present time the important producers of chrome ore are Turkey, New Caledonia, Rhodesia, Greece and Canada.

TABLE II

TYPICAL ANALYSES OF CHROMITE

	1	2	3	4	5	6	7
Cr_2O_3	56.8	48.1	54.5	58.1	42.6	53.1	32.9
FeO	12.1	14.8	19.5	27.6	13.8	15.3	13.0
Al_2O_3	15.0	12.5	11.0	3.8	8.3	8.0	8.3
MgO	14.0	16.5	8.0	3.2	21.1	16.1	24.6
SiO_2	1.5	6.2	3.1	5.1	9.5	6.4	14.0
CaO	0.7	....	1.5	....	....	1.2	....

	8	9	10	11	12	13	14
Cr_2O_3	40.7	33.2	39.5	52.7	34.5	42.5	48.4
FeO	16.6	14.6	15.8	14.2	14.2	15.0	14.4
Al_2O_3	24.3	28.8	26.2	12.5	19.0	16.8	12.1
MgO	14.9	n.d.	15.8	15.5	20.5	16.5	14.2
SiO_2	3.0	6.0	3.0	4.0	11.0	7.5	5.9
CaO	....	....	....	0.5	0.8	0.9	....

1, 2, Asiatic Turkey; 3, 4, New Caledonia; 5, 6, 7, Quebec; 8, Greece; 9, 10, Cuba; 11, 12, 13, California; 14, Rhodesia, South Africa.

The deposits of India, Cuba and Brazil have not been developed to any great extent but are potential sources of supply.

Deposits in the United States.—Chrome ore was first mined in California in 1880, and 2000 to 3000 tons annually were produced until 1895 to 1896. The output from that time until 1913–1914 was negligible. With the stimulus of higher prices during the war, California ores were again exploited, and the output rose to 63,000 tons in 1918. There are two main belts, one in the Klamath Mountains and the Coast Range from Siskiyou Co. to San Luis Obispo Co., the other in the Sierra Nevada Mountains from Plumas to Tulare Co. At places the black sands on the Pacific Coast contain considerable chromite.

Some of the Californian deposits contain up to 55% Cr_2O_3; others run as low as 20% in Cr_2O_3, and as high as 20% in SiO_2. Some of this is of such a nature that concentration is possible, and during 1918 and 1919 concentrators were operated at a few places, where the Cr_2O_3 content was brought to 40% or higher. Of the ore produced in the United States in 1918, 24% contained 45% or more Cr_2O_3; 55% contained between 35% and 45%; and 21% carried less than 35% Cr_2O_3.

Chrome is found in Southwestern Oregon, in the vicinity of Grant's Pass, and in the Northeastern part of the state, not far from Baker City. Chrome ore has been found at two points on the Kenai Peninsula, Alaska;

the ore reserves are reported to be about 30,000 tons in the one and 190,000 in the other. About 1000 tons were produced each year in 1917 and 1918.

There are a few small deposits near Burnsville, Democrat and Webster, North Carolina. Near Glenrock, Wyoming, a deposit of chromite has been found and worked on a small scale.

Uses of Chromite in the Metallurgical and Chemical Industries

The most important use of chrome ore is in the manufacture of ferro-chrome, the alloy of chrome and iron. It is usually prepared by direct reduction of the ore in the electric furnace.[1] For this purpose high grade ores are desired. Ferro-chrome usually contains over 60% Cr and .6% to 9.5% C; the physical characteristics of the alloy are governed by the amount of C present.

Ferro-chrome is used in making chrome steels. The amount of chromium in the steel may vary from 1% to 4% and the carbon from .5% to 2%. Chromium raises the elastic limit of the steel, increases the hardness, and intensifies the effect of other alloying elements. Chrome-nickel and chrome-manganese steels are not uncommon. Chrome steels are used for high-speed tools, armor plate, armor-piercing projectiles, crushing machinery, safes and automobile parts.

The principal chemical uses of chromite are in the manufacture of bichromate of soda, bichromate of potash, chromic acid (Cr_2O_3) and chrome alum, which are employed in the manufacture of dyes and pigments and for tanning leather.[2] For chemical purposes high grade ores containing over 50% Cr_2O_3 are desired. Chrome yellow, orange and green are used as dyes; chrome yellow, orange, red and green and Guignet's green, as pigments.

Cr_2O_3 is prepared by the action of a reducing agent upon sodium dichromate at fairly low temperatures. Its melting point is 1990 °C.[3] Metallic chromium may be prepared by the reduction of Cr_2O_3 by C in the electric furnace or by the thermit process. It is a very hard, non-magnetic, light green glistening crystalline powder. The specific gravity is 6.8[4] and the melting point 1520 °C.[5] It is stated[6] that metallic chromium has been used in the manufacture of high speed tool steel in place of ferro-chrome.

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[1] R. J. Anderson, "Metallurgy of Ferrochromium," *Eng. Min. Jour.*, **104,** 245 (1917); Lyon, Keeney and Cullen, "The Electric Furnace in Metallurgical Work," U. S. Bur. Mines, *Bull.* **77,** 127 (1916).

[2] J. S. Diller, "Chromite in 1917," *Mineral Resources of the U. S.*, **34** [1], 37 (1917).

[3] C. W. Kanolt, "The Melting Points of Refractory Materials," *Trans. Amer. Ceram. Soc.*, **15,** 167 (1913).

[4] H. Ries, *ibid.*, **104,** 988 (1917).

[5] G. K. Burgess and R. G. Waltenberg, "Melting Points of the Refractory Elements, I. Elements of Atomic Weight from 48 to 59," U. S. Bur. Standards, *Bull.* **10,** 85 (1914).

[6] J. C. Williams, "Chromite," *Min. Sci. Press,* **117,** 281 (1918).

Manufacture of Chrome Refractories

Foreign Practice.—A. B. Searle[1] has described the European methods of making chrome brick. Ores high in Cr_2O_3 are not generally used. A bonding material such as fire clay or lime is usually added to the pulverized ore; fire clay and kaolin are generally considered satisfactory, but are said to produce brick of lower melting point than those bonded with about 5% of lime. Other bonds which have been used or suggested are plaster of Paris; gypsum; 2% gypsum plus 1% aluminum sulphate; bauxite; 5% to 10% magnesia; 10% to 20% magnesite; 12% dolomite; hot tar; chromium salts, particularly potassium bichromate; various alkaline salts; clay with a little resin, coal or other carbonaceous matter. The purpose of adding the carbonaceous matter was to effect partial reduction of the ore to ferro-chrome.

The pulverized ore and bond are mixed with water in a trough mixer. In molding, a power press may be employed, or the material may be tamped by hand into iron molds. Drying is done slowly on a hot-floor. The brick are commonly, but not always, set in the same kiln with silica brick, and burned to cone 16 (1450°C) or higher.

The brick usually contain about 33% Cr_2O_3, although some grades contain over 60%. In the following analyses given by Searle,[2] brick C is stated to have about the average composition for British brick.

	A	B	C
Cr_2O_3	51.43	62.16	35.87
FeO	35.54	28.02	15.26
Al_2O_3	2.05	2.51	31.28
MgO	3.84	0.82	11.43
SiO_2	1.74	2.42	5.23
CaO	5.27	3.95	0.91

American Practice.—Ores of the following approximate analyses are used in the United States as refractory materials.

	A	B
Cr_2O_3	40.8%	44–48%
FeO	17.8	14
MgO	14.9	15
Al_2O_3	22.4	12
SiO_2	3.7	5 to 8

In the manufacture of brick, the use of any bonding material is not now customary in American practice. For that reason it is essential that the ore used be one which will bond strongly together at kiln temperatures, but without deforming or squeezing out of shape.

[1] Alfred B. Searle, "Refractory Materials," Charles Griffin & Co. Ltd., Pub., London (1917).

[2] Alfred B. Searle, *ibid.*

The ore, after being finely ground in a ball mill, is mixed with a small amount of water to the consistency of damp sand in a wet pan. The brick are molded either in a power press at high pressure or by hand. In the latter case the molds are filled by pounding with heavy plank mauls covered with metal. The brick are dried in tunnel driers. Both in the green and dried condition chrome brick are fragile and must be handled with great care. When set in the kilns for burning, they are boxed in with silica brick in such a way that there is hardly any load upon them and only 4 or 5 bricks are placed in a "box." They are burned in rectangular downdraft kilns, usually with magnesia brick. A burning temperature of cone 18 to 20 or slightly higher is customary; the permanent volume change in burning is negligible. Cooling of the kilns must be done slowly in order to avoid any cracking of the brick.

Properties of Chrome Brick

Properties in General.—The chief value of chrome brick lies in their chemically neutral character and their high refractoriness; their greatest disadvantages are their sensitiveness to rapid thermal change, and their inability to support heavy loads at high temperatures.

Chrome brick are shiny black in color. They are much heavier than fire clay or silica, and slightly heavier than magnesia brick; the weight of a chrome standard 9-inch brick, 9″ x 4½″ x 2½″, is between 10 and 11 pounds, and the bulk specific gravity is, therefore, 3.0 to 3.2.

The melting point of chrome brick, as determined by Kanolt is 2050°C.[1] The same observer found that magnesia brick melt at 2165°C and high-grade clay and silica brick at 1710°C. The analysis of American chrome brick is the same as that of the ore from which it is made. This has been given in the preceding pages.

Crushing Strength.—Chrome brick are very strong in the cold condition, having a crushing strength on flat of 3000 to 5000 pounds per square inch. However, they will not sustain a heavy load at high temperatures. G. H. Brown[2] found that a chrome brick of American manufacture, when set on end and heated, failed suddenly at 1450°C under a load of 50 pounds per square inch. The brick sheared diagonally into two parts, with no previous evidence of contraction. In the experiments of Mellor and Emory[3] a chrome brick under a load of 50 pounds per square inch failed suddenly at 1400°C. Magnesia brick, under the same load, in each case failed at a temperature of about 100°C higher than chrome brick.

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[1] C. W. Kanolt, "Melting Points of Fire Brick," U. S. Bur. Standards, *Tech. Paper* **10,** 15 (1912); *Jour. Gas Lighting,* **119,** 503 (1913); *Jour. Franklin Inst.,* **174,** 225 (1912); *Trans. Am. Electrochem. Soc.,* **22,** 95 (1912).

[2] G. H. Brown, "Notes on Load Test made on Magnesia, Chrome and Silica Brick," *Trans. Amer. Ceram. Soc.,* **14,** 391 (1912).

[3] "Effect of Load on the Refractoriness of Fire Brick," *Gas. J.,* **142,** 478 (1918).

The experiments of Bodin[1] indicate that the crushing strength of chrome brick is practically constant from room temperature up to 950°C, falling off rapidly above that point.

Modulus of Rupture.—The cross breaking strength of chrome brick is high for cold brick, but low at high temperatures. The average results of Hartmann and Koehler,[2] who investigated this property at 20° and 1350°C, are given in part below, for the materials which they used.

Material	Modulus of rupture, pounds per square inch 20°C	1350°C
Chrome Brick	1390	22
Magnesia Brick	1390	136
Silica Brick	550	161
Fire Brick—Grade A	665	113

Resistance to Abrasion.—Hartmann and Kobler[3] have made comparative abrasion tests on different kinds of refractory materials at ordinary temperatures and at 1350°C. The amount of abrasion was measured by determining the depth abraded in 5 minutes by a carborundum cutting wheel at a constant pressure.

It seems probable that the magnesia and chrome brick used in this test were not of the usual commercial grade, but were of the same quality as those used by Hartmann and co-workers in their study of electrical resistivity.[4] In that event the figures quoted will not apply to the usual magnesia and chrome brick on the market. Moreover, a more accurate method for determining abrasion at 1350°C should have been chosen. The brick were heated on one end, being inserted while cold in the wall of a furnace which had been previously brought to 1350°C, and kept there for two hours. After heating, the brick were removed quickly and while still hot were held for three to five minutes against a cutting wheel. The temperature changes involved in the heating up and testing were too rapid for such materials as chrome, magnesia and silica brick, and undoubtedly caused some cracking and lowered the resistance to abrasion.

The results, in part, are as follows:

Material	Cold Depth of cut, inches 5 Minutes	1350°C Depth of cut, inches 5 Minutes
Chrome Brick	0.07	0.27
Magnesia Brick	.05	12.5
Silica Brick	.17	Spalled
Fire Brick—Grade A	.26	.11

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[1] V. Bodin, "Tests on Refractory Products under Load at Different Temperatures," *Trans. Ceram. Soc.* (British), **21** [1], 43(1921–22).

[2] Hartmann and Koehler, "Physical Characteristics of Specialized Refractories, Pt. IV: Cross Breaking Strength 20° and 1350°C," *Trans. Am. Electrochem. Soc.*, **39**, 129 (1921).

[3] Hartmann and Kobler, "Physical Characteristics of Specialized Refractories, Pt. II: Comparative Cold and Hot Abrasion Tests," *ibid.*, **37**, 717 (1920).

[4] See remarks under this heading on p. 877.

Thermal Conductivity.—No accurate studies have been published concerning the thermal conductivity of chrome brick. However, it is known to be considerably higher than that of clay and silica, and slightly lower than that of magnesia brick.

No figures are available concerning the specific heat.

Electrical Resistivity.—Stansfield, MacLeod and McMahon[1] and Hartmann, Sullivan and Allen[2] have compared the resistivity of various refractories at high temperatures.

TABLE III

ELECTRICAL RESISTIVITY IN OHMS PER CM.[3]

Temperature, °C	Chrome brick		Magnesia brick		Silica brick		Fire brick	
	A	B	A	B	A	B	A	B
Cold	....	48.1×10^6	....	137×10^6	....	125×10^6	....	137×10^6
600°	....	...	....	....	....	....	21000	....
700°	....	...	....	....	....	....	17000	....
800°	2800	803	....	5.00×10^6	....	2.38×10^6	13000	57600
900°	760	525	....	1.24×10^6	....	765000	9000	20600
1000°	420	171	....	708000	....	300000	6600	10800
1100°	430	78	....	560000	....	126000	4400	6590
1200°	450	63	....	193000	....	62000	2300	4160
1300°	410	77	6200	67400	9700	30900	1300	2460
1400°	320	85	420	22400	2400	16500	690	1420
1500°	....	41	55	2500	710	8420	280	890
1550°	....	...	30	....	22	....	60	....
1565°	....	...	25	....	18	....	....	....

A—Stansfield, MacLeod and McMahon.

B—Hartmann, Sullivan and Allen; figures are for ascending temperatures.

The chemical analyses of the brick studied by Hartmann and co-workers are given as follows:

	Chrome brick	Magnesia brick	Silica brick	Fire brick
SiO_2	15.8	6.0	94.8	50.4
Fe_2O_3	....	0.3	0.2	0.8
FeO	13.2	....	....	....
Al_2O_3	7.3	6.3	1.8	45.5
CaO	....	3.1	2.4	0.5
MgO	18.5	84.1	0.3	0.8
TiO_2	....	....	....	1.9
Cr_2O_3	40.9	....	....	....

It will be observed that the results obtained by the two groups of workers are far from agreement. Stansfield, MacLeod and McMahon have indicated that the probable error of their determinations is less than 5% or 10%

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[1] A. Stansfield, D. L. McLeod and J. W. McMahon, "Electrical Resistance of Fire Bricks at High Temperatures," *Trans. Amer. Electrochem. Soc.*, **22,** 89 (1912); *Met. Chem. Eng.*, **10,** 746 (1912).

[2] Hartmann, Sullivan and Allen, "Physical Characteristics of Specialized Refractories, Pt. III: Electric Resistivity at High Temperatures," *Trans. Amer. Electrochem. Soc.*, **38,** 279 (1920).

for reading under 6,000 ohms, rising to a maximum probable error of 25% at 21,000 ohms; also that the results for chrome brick are subject to correction. Hartmann, Sullivan and Allen state that their results cannot be regarded as average values, on account of differences in different specimens of brick, but that they serve to indicate the relative order of magnitude of the electrical resistivities up to 1500°C. They have shown that for some refractories there is a considerable change in resistivity with time of heating.

The analyses indicate that the tests of Hartmann and co-workers were not made upon chrome and magnesia brick of the grade generally used commercially. The chrome brick, for example, contained 15.8% SiO_2 and 7.3% Al_2O_3, which are not typical and the magnesia brick contained only .3% Fe_2O_3 instead of the customary 6.5%.

Effect of Temperature Changes.—At furnace temperatures, the thermal expansion of chrome brick is approximately .20″ per foot. When subjected to rapid temperature changes chrome brick have a tendency to crack and pieces may spall off. Furnaces in which chrome brick are used should be heated slowly and carefully.

Chemical Behavior.—The most useful property of chrome brick is their nearly neutral chemical character, which renders them highly resistant to the action of the usual metallurgical slags, either acid or basic. One of their most common uses is the separation of other refractory materials which react chemically with each other at high temperatures.

Molten silica has a fluxing action upon chrome brick, and carbon has a reducing effect at high temperatures. However, unlike carbon, chrome may be exposed to either an oxidizing or a reducing furnace atmosphere without injury.

Uses of Chrome Refractories

Steel Industry.—In the basic open hearth furnace, the use of chrome brick to separate the acid and basic portions of the refractory structure is undoubtedly good practice. A course of chrome brick between the silica and magnesia brick in the side walls, and between the clay and magnesia brick in the refractories underlying the working bottom, will prevent chemical reaction between the magnesite and the other refractories. It has been shown that at approximately 2775°F magnesia and fire brick react with the formation of a thin liquid slag. With magnesia and silica brick, the reaction is less violent and appears to begin at about 2900°F.

The open hearth port walls are frequently built of chrome brick, which cut away less rapidly than silica brick, and therefore, keep the port section more nearly uniform.

Lump chrome ore has not been found satisfactory as a bottom material in the open hearth, but is sometimes employed in building up the slopes or blocks at the ends of the furnace. Spaces between the larger lumps are filled with smaller lumps and finely ground ore, and the surface is daubed over with the fine material. Ground chrome ore is used also for ramming around the tap hole; for patching and daubing around the jambs and ports, and in the paving of the ports; and for daubing on the side walls from the slag line to the top of the walls. This is done in order to protect the walls from corrosive spray. Practice varies considerably; some plants use no ground chrome ore, others as much as 2 to 3 pounds per ton of steel produced. There is a great difference in the serviceability of different grades of chrome ore for this practice.

In soaking pits, heating and heat treating furnaces and certain other furnaces, iron oxide scale is formed which has a strongly corrosive action upon fire brick or silica brick. In the portion of the furnace where this scale collects, chrome brick are frequently used.

In forge and welding furnaces, fire clay brick have a short life, on account of the corrosive action of the iron oxide scale; chrome brick in the bottoms last many months. Chrome brick are superior to magnesia in these furnaces, being less sensitive to rapid temperature changes.

Copper Industry.—In the metallurgy of copper, both chrome ore and brick have been successfully applied as lining materials in blast furnaces, settlers, matte reverberatories, and refining furnaces.

Blast Furnace.—The blast furnace crucible is generally made of fire brick, although with a very corrosive matte, low in copper, chrome brick are considered an economy.[1] In 1901 Wm. Glenn reported the successful use of chrome ore in the crucible hearth. A 12-inch bottom was built up of chrome ore lumps and fines; above this a course of fire brick was laid on end, giving a depth of 8″ to be dissolved before the matte reached the chrome. At the end of two years the bottom was reported to be still in good condition.[2] Chrome brick have been used in the blast furnace hearths at Douglas, Arizona,[3] and in the plant of the Mond Nickel Co., Conniston, Ontario. At Conniston the chrome lining is 25 inches thick.[4]

Settlers.—It has been reported that chrome brick in the blast furnace settlers, or fore-hearths, last two years at the Douglas plant. The method of lining the settler used at Cananea in 1908 has given exceptionally good results.[5] The bottom consists of 10 inches of fire brick throughout, except for a $2^1/_2$-inch paving of chrome brick in small areas beneath the spout and around the tap hole. A 9-inch thickness of chrome brick in the side walls is backed up by a mixture of crushed quartz and clay, called "converter lining." The function of the "converter lining" is to decrease loss of heat by conduction and to diminish strains on the steel shell by taking up the expansion of the brick.

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[1] H. O. Hofman, "Metallurgy of Copper," McGraw-Hill (1914).

[2] Wm. Glenn, "Chromite as a Hearth Lining for a Furnace Smelting Copper Ore," *Trans. Amer. Inst. Min. Eng.*, **31**, 374 (1901).

[3] F. R. Pyne, "Notes on the Disadvantages of Chrome Brick in Copper Reverberatory Furnaces," *ibid.*, **59**, 151 (1918); *Met. Chem. Eng.*, **18**, 20 (1918); *Min. Sci. Press*, **46**, 60 (1918).

[4] "New Smelting Works of the Mond Nickel Co.," *Eng. Min. Jour.*, **98**, 1050 (1914).

[5] Charles Shelby, "The Cananea Blast Furnace," *Ibid.*, **85**, 841 (1908).

In lining the settlers at one of the western smelters, a 9-inch wall of inexpensive clay brick is first built within the shell, leaving an open space between the brickwork and the shell. This space is 6 inches wide at the top and 14 inches wide at the bottom. Upon completion of the brick wall, the open space is tamped full of chrome ore, ground to pass a 4-mesh screen. After the lining has been placed in use, the slag probably eats away the brick lining gradually, but has little effect on the chrome, which sinters solidly together. Settlers lined in this way have been operated many years with no repairs.

B. Magnus[1] reports that blocks of high-grade chrome ore, with a hole drilled through the center, have been used as tapping hole blocks in settlers, with good results both for high and low grade mattes.

At Silverspur, Australia, chrome ore dry masonry has been successfully used for the sidewalls and bottom of a reverberatory furnace producing a highly basic slag. The chromite lumps gradually wore away through the breaking off of small particles. These were too heavy to float on the slag and too light to sink into the matte, and formed a layer of chrome sand between slag and matte. This layer interfered with the working of the furnace as it could not be skimmed out with the slag, nor tapped out with the matte, but had to be skimmed out separately at regular intervals. Difficulties were encountered in the attempt to recover the metal absorbed in the bottoms and skimmed sands.[2]

In matte reverberatory furnaces the use of magnesia or chrome brick along the slag line was at one time common, but this practice was gradually discontinued as side-charging of the furnaces became general. When this method of charging is employed the refractory walls are protected from the action of the corrosive slag by the banks of pulverized ore.

Converters.—Chrome brick have been used to a slight extent in converter linings, although magnesite is the standard refractory for this purpose. Lathe reported in 1910[3] that at the Granby smelter, Anyox, B. C., the converters were lined with chrome brick next to the shell, with magnesia brick only around the tuyeres. At Huaron, Peru, several converters with magnesia linings have chrome brick around the tuyeres.

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[1] B. Magnus, "Chrome Ore Tapping Blocks for Blast Furnace Settler," *Eng. Min. Jour.*, **101**, 778 (1916).

[2] Edgar Hall, "Chromite Iron Ore as Lining for Reverberatory Furnaces," *Eng. Min. Jour.*, **101**, 267 (1916).

[3] Frank E. Lathe, "Recent Developments at the Granby Smelter," *Canadian Min. Inst.*, **13**, 283 (1910).

Refining Furnaces.—For many years chrome brick have been used in refining furnace linings in the Copper Range, Michigan. They are placed around the tap hole and along the slag line for several courses. After about a year's run, the walls are customarily torn down for repairs; the chrome brick are cleaned and the good ones used again.

Francis R. Pyne[1] has reviewed the results obtained from magnesia and chrome brick at an eastern refinery treating very foul blister copper. It was expected that a basic or neutral lining would last longer than silica and decrease the amount of slag formed. Magnesia brick were not sufficiently resistant to the rapid changes in temperature which took place in certain parts of the furnace. Although they withstood the corrosive action of the slag, they cracked and spalled badly. Chrome brick were substituted, and at first seemed to give such good results that they were adopted in all refining furnaces at the plant, both those treating blister copper and those melting cathodes. In a number of furnaces even the silica roofs were replaced by chrome. Eventually, however, it was found that the amount of metal absorbed by the chrome brick was very high. Attempts to recover the values locked up in the scrap ends of chrome brick were not successful. The most satisfactory disposition found for these scrap ends was to grind them up and make them into brick, and thus use them over. There was no difficulty in recovering the values from magnesia brick. Mr. Pyne reached the conclusion that chrome brick are not desirable for refining furnace use, and that magnesia brick should be employed where possible. The difficulty of recovering absorbed metal from chrome had been previously mentioned by Edgar Hall.[2] After considerable experimental work at Silverspur, Australia, it was found that the chrome residues, after being finely ground, could be readily smelted in a lead blast furnace.

At one of the smelters in the Copper Range the construction of the refining furnace roof is unique. Silica brick are laid so as to give a roof $13^1/_2$ inches thick. The joints are made $^3/_{16}$- to $^1/_4$-inch thick and filled with chrome ore ground from 60- to 80-mesh fineness. When laid in this manner the brick resist the corrosive action of the splashing copper much better than when laid in the ordinary way with knife-edge joints. With the ordinary method of laying, corrosive action begins at the joints; these wear back rapidly, leaving the ends of the brick projecting, and giving the arch a "saw-tooth" appearance. With the chrome ore joints there is little if any such action at the joints, and the entire arch wears back evenly and smoothly.

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[1] F. R. Pyne, *loc. cit.*

[2] Edgar Hall, *loc. cit.*

Miscellaneous.—Chrome ore and brick have been used with some degree of success in various furnaces in the smelting and refining of lead, antimony, tin and nickel. Chrome is said to offer greater resistance than magnesia to the corrosive action of the oxides of bismuth, antimony, arsenic and tin.[1]

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[1] M. Simonis, *ibid;* F. T. Havard, "Refractories and Furnaces," McGraw-Hill Book Co., Pub. (1912); F. T. Havard, "Recent Development in the Refractory Industry," *Trans. Amer. Ceram. Soc.,* **14,** 480 (1912); "Effect of Load on the Refractoriness of Fire Bricks, *Gas. Jour.,* **142,** 478 (1918).

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COMPARISON OF HOT AND COLD MODULUS OF RUPTURE FOR SILICA BRICK

By E. N. McGee[1]

ABSTRACT

Purpose of the Investigation.—(1) To obtain relative values for the cross-breaking strength of silica brick at temperatures encountered in coke oven practice.

(2) To correlate the hot modulus of rupture test, if possible, with the cold modulus of rupture, or cold crushing test, either of which is cheaper and more easily conducted.

This report gives the method of making the test, difficulties encountered and results obtained. The report shows a comparison of cold crushing, cold modulus of rupture and hot modulus of rupture on a series of silica brick made from special mixes, commercially burned.

Conclusions.—The modulus of rupture of a silica brick at 1350°C is approximately one-third the strength at atmospheric temperature. For this series it averaged from 130 to 189 lbs. per square inch.

Too rapid or eccentric heating up to red heat may cause such weakening of the structure or bond that the brick will break under very low pressure.

Cross-breaking strength decreases as the temperature increases.

Hot modulus of rupture test appears to give results, in most respects, comparable to the cold test, and for routine testing it would seem advisable to use the cold test since it can be made in much shorter time.

Introduction

Silica brick were first introduced in by-product coke oven construction in the United States at Johnstown, Pa., in 1899. The success of this refractory from the beginning was so remarkable that within a few years it became the common practice to use silica brick in nearly all parts of the coke oven block. Clay brick are used only where the temperature requirements are low, where there are repeated rapid temperature fluctuations or as a veneering to absorb temperature changes.

The principal advantage obtained from the use of silica brick lies in the higher temperatures at which the ovens can be operated. This results in a much faster coking rate, and, consequently, a much greater coke tonnage and gas yield. The reason that these results can be obtained is not because silica brick are more refractory than clay brick, for there are many of the latter refractory having a higher fusion point by 50°C or more. Nor can these results be entirely due to the fact that silica brick conduct heat more rapidly than clay brick. The principal characteristic which has made silica brick so valuable to the coke oven industry lies in their ability to carry heavy loads at very high temperatures without deformation or crushing.

The best clay brick show deformation at 1350°C if subjected to a load of 25 pounds per square inch. If supported on other brick, at both ends, seven inches in the clear, and loaded with a five-pound fire brick in the center, and subjected to a temperature of 1450°C, the best clay brick show a bending of from one-fourth to three-eighths of an inch. Silica brick, on the other hand, show no deformation at 1350°C under a load of 50 pounds per square inch, and no bending on any test which has yet been made. In fact, it is undoubtedly true that they would show no deformation at any load, up to the crushing point, or any bending up to the breaking point. These are the deciding factors which have necessitated the use of silica brick in present coke oven practice, where the ovens are operated normally with a flue temperature of 1350°C, and may, under abnormal conditions, reach 1500°C.

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[1] Refractories Division, St. Louis Meeting, Feb. 28, 1922.

Purpose of This Investigation

The cold crushing and cold modulus of rupture tests have served as the standard tests for judging the strength of silica brick and determining their suitability for service in vital parts of coke oven construction. The load which they will carry at the temperature at which ovens are operated has not been considered important because the construction engineer has relied upon the cold tests and found them satisfactory so far as it has been possible to determine. Whether or not the hot and cold strengths of silica brick are comparative is, however, of considerable importance, and is the main reason for this investigation. The second purpose of this investigation is to obtain definite information on the cross-breaking strength of silica brick at temperatures encountered in coke oven practice.

The tests, upon which this investigation is based, were made upon a series of experimental brick obtained from a well-known manufacturer, and since these were special brick, they were consequently as uniform in every way as it was possible to make them. Cold modulus of rupture and cold crushing tests were made at the Mellon Institute of Industrial Research, Pittsburgh, Pa., under the direction of Mr. R. M. Howe. The average of ten samples was taken for each mix of the series. Mr. Howe also attempted to obtain the hot crushing strengths at 1450°C, but furnace conditions prevented this, and we have not as yet obtained satisfactory results for the hot crushing strengths of this series of experimental brick. It is interesting to note that the crushing strength at 1450°C was found to be approximately 300 pounds per square inch.

Description of Apparatus for Hot Modulus of Rupture Test

The hot modulus of rupture tests were conducted at the Refractory Testing Laboratory of the Semet-Solvay Company, Syracuse, N. Y., in a furnace of the design recommended by the American Society for Testing Materials for the testing of refractory materials under load. (Fig. 1.) The tests were conducted at a temperature of 1350°C. This was found to be a very good working temperature and approximated existing conditions common in oven flue temperatures. The furnace was fired by two tangential 2-inch burners using unpurified coke oven gas.

Two piers (C-C of Fig. 1) were built up from the bottom of the furnace out of carborundum brick so that they were directly under the openings (A-A) in the top of the furnace. These piers reached within 9 inches of the furnace top and were so arched at the bottom that the flame from the gas burners could pass through and circulate in the interior of the furnace. The two test brick rested on these piers on two pieces of carborundum (B-B) approximating as nearly as possible knife edges and so placed as to make a 6-inch span and have the center of the brick surface come underneath the opening in the furnace cover. A carborundum tube (S-S) (silfrax in this case) 5 inches long was laid across the middle of the brick span and served as the knife edge carrying the pressure. A

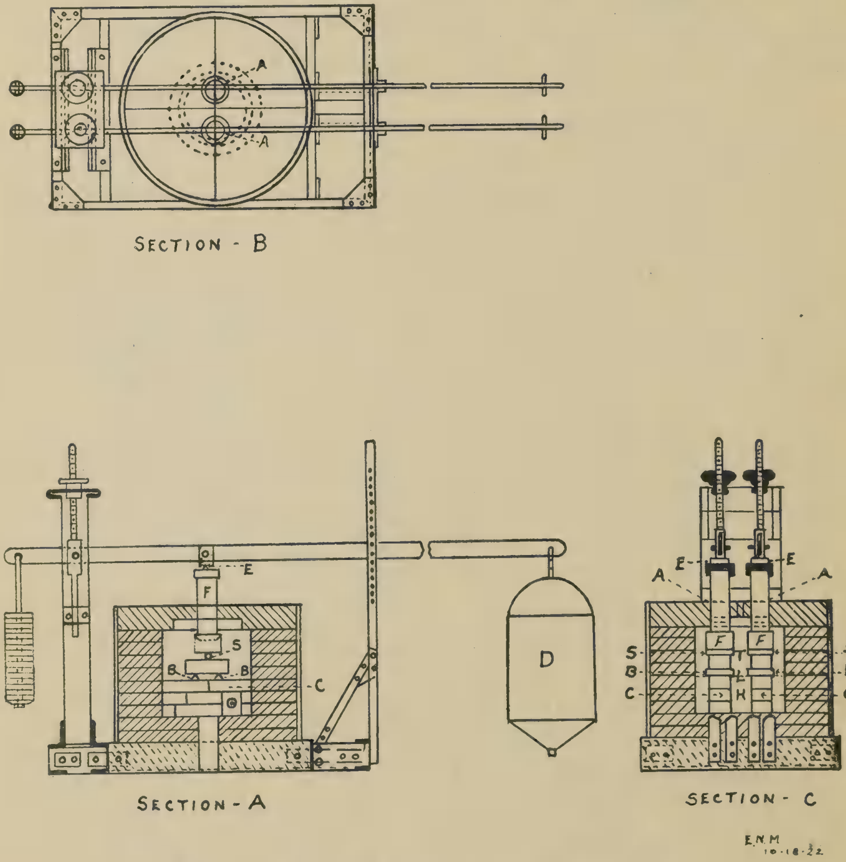

FIG. 1.—Apparatus for hot modulus of rupture test.

large can (D) 18 inches in diameter and 2 feet high, cone-shaped at the bottom, was hung on the end of the beam and gradually filled with water until the brick broke, thus giving, with fair degree of accuracy, the breaking load. The load was conducted to the brick from the beam through a steel knife edge (E), a highly refractory clay cylinder (F) and the carborundum tube (S) mentioned before. The beam was countered-balanced but the other materials formed a part of the breaking load, and their weights were taken into consideration.

Method of Conducting Test

In developing this test considerable difficulty was encountered in heating the test brick from atmospheric temperature to red heat without causing spalling or otherwise injuring the strength of the brick. Since it was necessary to complete the test in eight hours, the heating had to be quite rapid. With the arrangement as described it was found almost impossible to get any good tests. The bricks would usually break at very low pressures, and sometimes even before the temperature reached 1350°C with only the weight of the empty can on the beam. The difficulty of controlling the temperature up to 500°C so as to give a very gradual increase was no doubt the cause of the weakening of the brick. There was no shattering but it appeared that the uneven heating merely weakened the structure.

To correct this condition it was found necessary to fill in between and around the carborundum piers with pieces of carborundum brick and cement, thus dividing the furnace into two compartments (indicated on Section C of Fig. 1); a testing chamber (T) above, and a heating chamber (H) below the brick filling, represented by dotted lines (L). This prevented the flame from playing directly upon the test specimens and made it a much more simple matter to obtain a uniform and consistent increase of temperature in the testing chamber even though there were quite erratic temperature fluctuations in the heating chamber. After making this change, very few inconsistent results were obtained, and those were undoubtedly due to the structure of the brick rather than uneven heating.

Heating Schedule

The following heating was used and proved very satisfactory.

Time		Temperature of testing chamber	Time		Temperature of testing chamber
Hr.	Min.		Hr.	Min.	
0	0	25°C	4	0	700°C
	15	100		15	800
	30	150		30	900
	45	200		45	1000
1	0	230	5	0	1100
	15	260		15	1150

TABLE (*Continued*)

Time		Temperature of testing chamber	Time		Temperature of testing chamber
Hr.	Min.		Hr.	Min.	
	30	300		30	1200
	45	330		45	1250
2	0	360	6	0	1300
	15	400		15	1325
	30	430		30	1350
	45	460		45	1350
3	0	500	7	0	1350
	15	550		15	1350
	30	600		30	1350
	45	650			

Temperature Control

The temperature of the testing chamber was controlled by means of a platinum rhodium thermocouple. The couple and porcelain protection tube were placed in a carborundum (Silfrax) tube and projected about 6 inches into the furnace chamber. The couple connected with a Wilson-Maeulen Tapalog and was equipped with cold end compensating leads. The temperature of the test specimens was also checked occasionally by means of a Leeds and Northrup optical pyrometer. When the temperature reached 1350°C it was maintained about one hour until the bricks were uniformly heated and then the load was gradually increased until the brick broke.

Data

The standard formula $R = \frac{3WL}{2B(d)^2}$ was used for computing the modulus of rupture. The following are the results which were obtained, the letters representing the various brick mixes used in this experimental series:

TABLE I

AVERAGES OF RESULTS OBTAINED

Mix	Cold crushing strength, 9-in. straights	Cold modulus of rupture, 9-in. straights	Hot modulus of rupture, 9-in. straights
A	1650 (1270–2200)	418 (298–486)	167 (162–170)
B	1580 (1320–1910)	449 (349–502)	175 (167–186)
C	1680 (1270–1950)	464 (355–550)	189 (155–229)
D	1360 (1080–1700)	465 (294–626)	180 (167–195)
E	1360 (1150–1760)	435 (317–534)	156 (145–167)
F	1320 (950–1650)	438 (358–586)	156 (143–178)
G	1580 (1040–2090)	486 (298–637)	150 (145–157)
H	950 (640–1240)[1]	462 (336–605)	137 (133–146)
I	990 (640–1240)[1]	404 (209–407)	130 (115–135)

[1] Average of 5 tests instead of 10.

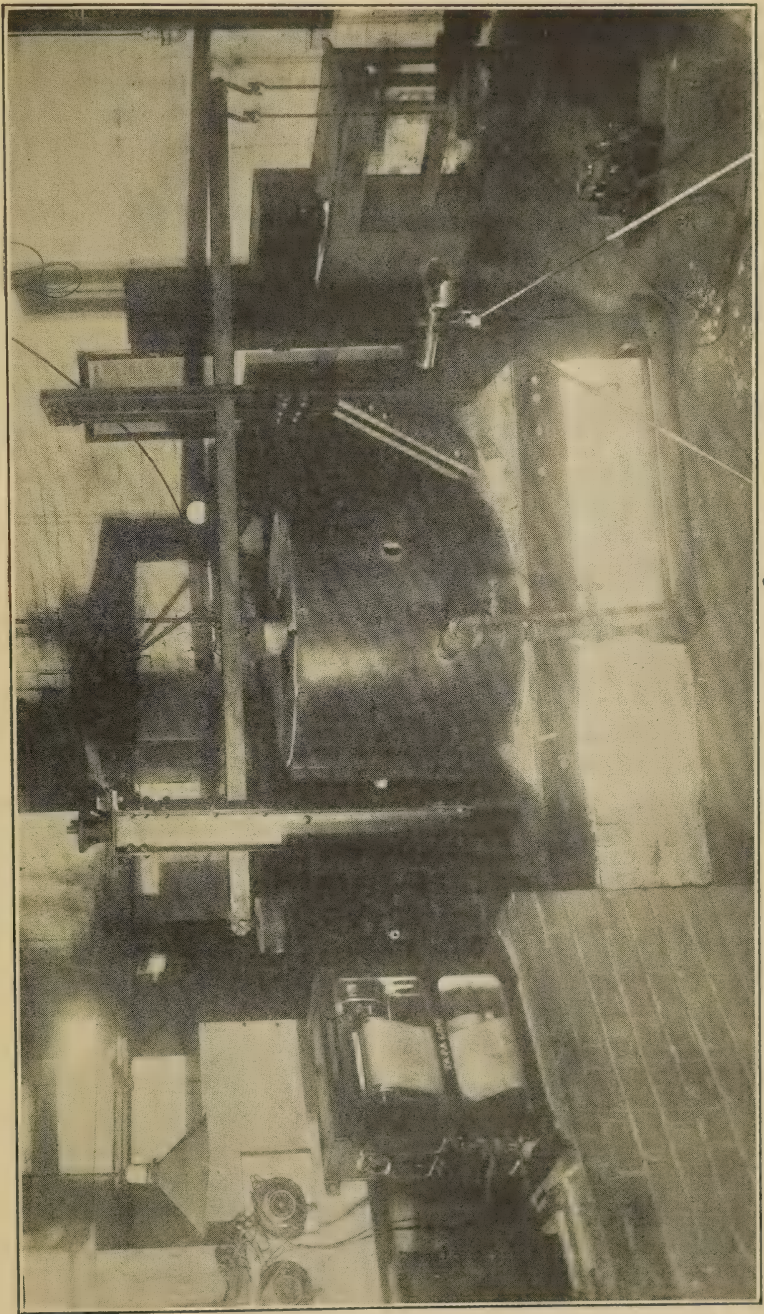

FIG. 2.—Load test furnace—used for hot modulus of rupture test.

Conclusion

In comparing the hot with the cold modulus of rupture test it is difficult to obtain any definite conclusion from the results which have been obtained. Both the hot and cold tests showed considerable variations in strength with the same mix, in fact, in most cases, the difference between the highest and the lowest result in each mix was as great or greater than the highest and lowest of the mix averages. Also in most cases the averages on the hot modulus of rupture are only of three results, and such averages cannot be considered accurate. It will be seen from Table II, however, that with the exception of mix C, the results were fairly uniform. Results marked with footnote appeared to be inconsistent and consequently it did not seem advisable to take them into consideration. Most of these results were obtained before the change in the furnace design and were probably due either to eccentric loading or too rapid heating, causing a shattering or weakening of the bond.

TABLE II

COLD CRUSHING TESTS

	A	B	C	D	E	F	G	H	I
	1420	1470	1880	1700	1300	1030	1250	1060	900
	1560	1630	1630	1180	1750	1210	2450	1050	1240
	1820	1640	1800	1470	1270	950	1580	790	640
	1760	1560	1950	1300	1760	1470	2120	800	1180
	1730	1360	1670	1080	1280	1220	1360	1030	980
	2200	1740	1830	1660	1250	1280	1040	..	..
	1560	1320	1490	1380	1290	1170	1560	..	..
	1680	1650	1270	1090	1190	1640	1240	..	..
	1270	1910	1800	1200	1150	1560	1130	..	..
	1470	1530	1440	1580	1400	1650	2090	..	..
Av.	1650	1580	1680	1360	1360	1320	1580	950	990

Although the results as obtained do not permit us to draw any definite conclusion regarding the relation of the hot modulus of rupture to the cold modulus or cold crushing tests, still this investigation does present some interesting and valuable conclusions. It shows, in the first place, that the cross-breaking strength of a brick at 1350°C is approximately one-third the strength at atmospheric temperature, and somewhat lower than had ordinarily been supposed from results obtained on previous load tests, although still considerably higher than should ever be encountered in coke oven practice. Some recent furnace constructions of special design, in which the load was extraordinarily high, have caused crushing of the silica brick, showing that the strength of a brick at high temperatures is an important factor which must be taken into consideration.

The investigation also shows conclusively that silica brick require very uniform and careful heating up to red heat. Erratic heating may cause

TABLE III

MODULUS OF RUPTURE RESULTS—COLD AND HOT TESTS

A		B		C		D		E		F		G		H		I	
Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot
445	170	419	186	400	183	505	195	534	167	358	178	618	148	381	146	442	126
349	162	470	172	550	155	554	167	445	145	506	143	637	157	422	140	403	135
374	170	496	167	518	229	556	178	454	156	384	145	557	145	336	133	448	115
298	...	355	338[1]	406	53[1]	294	...	438	110[1]	419	185	502	40[1]	445	52[1]	400	143
448	...	349	72[1]	355	63[1]	416	...	317	42[1]	493	130	419	47[1]	576	...	416	47[1]
467	...	486	...	556	...	576	...	422	...	416	...	298	...	499	...	400	...
448	...	486	...	384	...	371	...	493	...	586	...	467	...	339	...	467	...
486	...	467	...	509	...	429	...	451	...	438	...	320	...	528	...	429	...
445	...	502	...	438	...	626	...	435	...	397	...	592	...	605	...	269	...
...	...	464	...	521	...	320	...	358	...	384	...	451	...	490	...	362	...
418	167	449	175	464	189	465	180	435	156	438	156	486	150	462	137	404	130

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[1] Results which appeared irrational and were not considered in computing averages.

such weakening of the structure or bond that the brick will break under very low pressures.

From four tests on samples from this series conducted at temperatures below 1350°C the following results were obtained:

Temperature	Sample	Modulus of rupture
1300°C	"B"	199 lbs. per sq. in.
1300°C	"F"	185 lbs. per sq. in.
1200°C	"C"	289 lbs. per sq. in.
1150°C	"G"	285 lbs. per sq. in.

Comparison of these results with those at 1350°C would seem to indicate that the cross-breaking strength of a silica brick decreases as the temperature increases. Undoubtedly if tests were conducted at temperatures above 1350°C, correspondingly lower results would have been obtained.

The method used in making these hot modulus of rupture tests requires a great deal of time and attention. If such tests were required for determining suitability of brick for certain construction, it would seem advisable to use a rectangular, gas fired furnace of sufficient size and so equipped as to test at least five brick at one time. Ten samples would probably be required to give an accurate average. The furnace would of course have to be uniform in temperature throughout and a much slower heating schedule would give better results, in fact, twenty hours would be about the time required to reach 1350°C, heating at the rate of 50° per hour from 200 to 700°C. This would insure that the strength of the brick would not be affected by erratic heating.

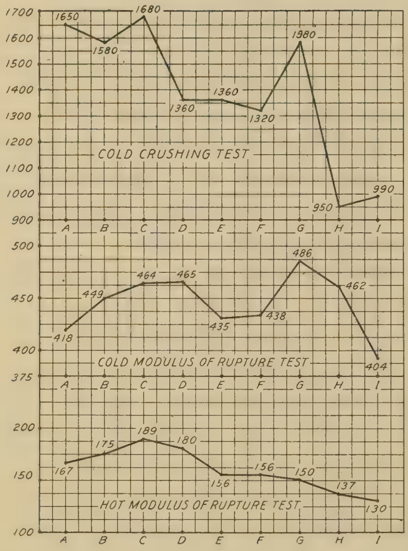


Fig. 3.

The hot modulus of rupture appears, however, as mentioned before, to give results in most respects comparable to the cold test and for routine testing the cold test, which can be made in a much shorter time, would seem to give a fair indication of what can be expected in actual practice.

Semet-Solvay Co.
Syracuse, N. Y.

Discussion

Mr. Whitten:—I would like to ask the following questions: (1) Has any comparative work been done on silica brick and clay brick, taking into consideration the fact that the silica brick must still be a sound brick at 1400 or 1500 °C? (2) Is there any relationship between the modulus of rupture and the resistance to wear or erosion? (3) How do clay and silica brick check in these respects?

DR. HARVEY:—So far as I know these are the first tests that have been made on hot modulus of rupture of silica brick. For several years a hot transverse test has been made by loading with five pounds weight in the center. If the brick was weak it would break, but ordinarily refractory bricks would simply bend. Mr. McGee and I have discussed the possibility of extending this same series of tests to clay brick, and the question arose as to whether the clay brick would break or simply bend at these operating temperatures. I do not believe that a hot modulus test has been made on clay refractories.

DR. ENDELL:—Mr. Bodin[1] has reported investigations of this sort but I believe his 20 mm. cubes were too small, causing the applied load to be too light. He found the point of decline in resistance, *i. e.*, point where the refractories are in an intermediate, more or less "pasty" state, is at about 1200 °C. His exact figures for the different refractories are:

Clay A	1300 °C	Bauxite	1100 °C
Clay CL	1200 °C	Silica bricks	1400 °C
Clay P	1100 °C	Fused quartz	1400 °C
Corundum	1400 °C	Magnesia	1000 °C

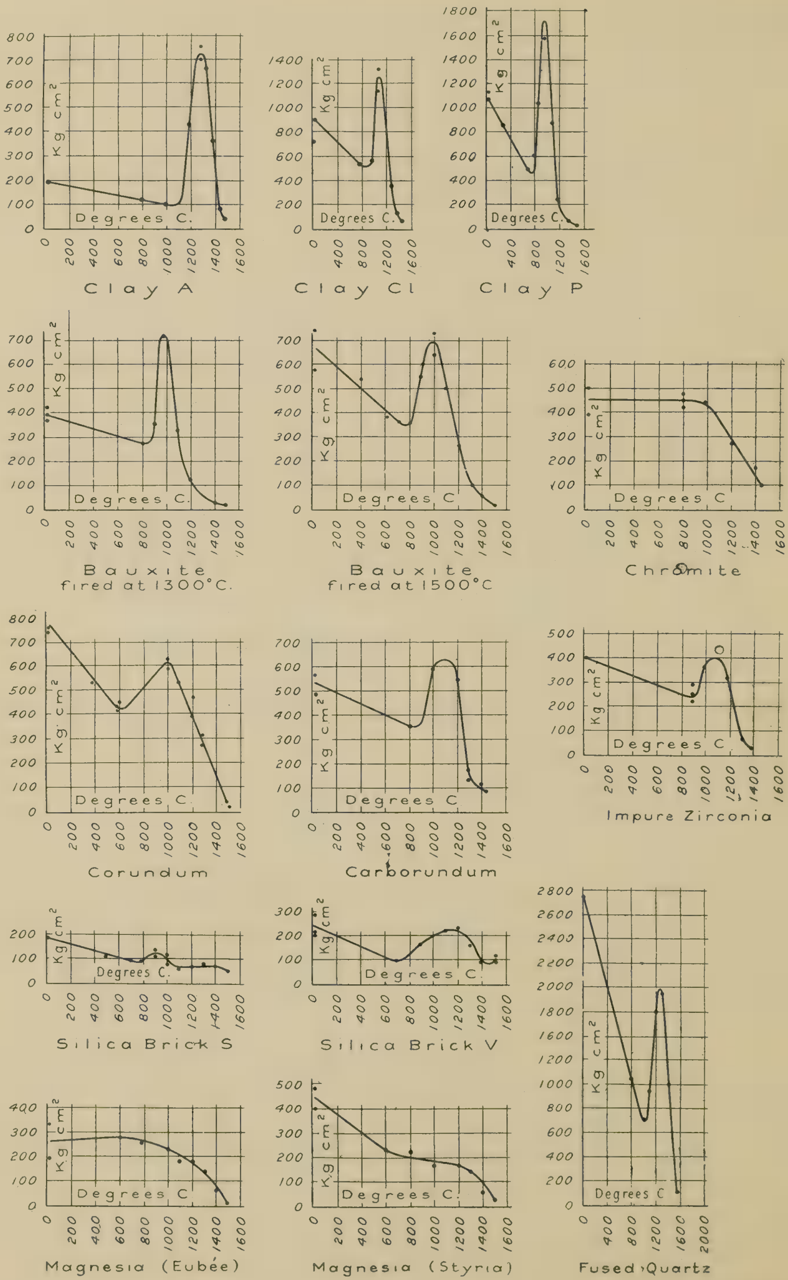
I believe also there is a mistake in his apparatus. It is not possible to test accurately at a pressure of 18 pounds to the square inch. I made this same sort of an investigation, only I put 50 pounds to the square inch, and the temperature of softening was much lower.

MR. GREAVES-WALKER:—Here are the Bodin curves and the line drawing of the apparatus used by Mr. Bodin (Figs. 4 and 5). These curves[2] show that practically all refractories pass their weak stage at various temperatures from cold to their softening point, and practically every kind of refractory, outside of chrome, shows a very erratic curve. For instance, clay brick shows little change up to 800° and then rises rapidly to a strength far above its cold crushing strength and then collapses. The silica curve shows they are weaker at certain points and take on greater strength at 1100 to 1200°; they are even stronger at that point than when they are cold and then they slowly fall.

MR. McGEE:—We have also the test mentioned by Dr. Harvey, which we call the bending test; the bend takes place at a temperature lower than the usually observed softening point because, we take it, the bricks are more plastic at this lower temperature.

[1] *Trans. Ceram. Soc.* (Eng.), **21** [1], 56 (1921).

[2] See also Schurect, "Note on the Effects of Firing Temperature on Strength of Fire Clay Bodies, **4**, 366(1921).



Clay A

Clay Cl

Clay P

Bauxite fired at 1300°C.

Bauxite fired at 1500°C

Chromite

Corundum

Carborundum

Impure Zirconia

Silica Brick S

Silica Brick V

Magnesia (Eubée)

Magnesia (Styria)

Fused Quartz

FIG. 4.

MR. HULL:—We have at the Bureau a very definite problem in connection with certain processes that our Chemistry Division is trying to work out, in which the processes could be very greatly improved if they could find a refractory which could withstand a pressure of 25 pounds per square inch at a temperature of 1600°C. If they could get one which would stand 1700°C, they would have a very great increase in efficiency, but we are still looking for one which will stand 1600°C. It may be

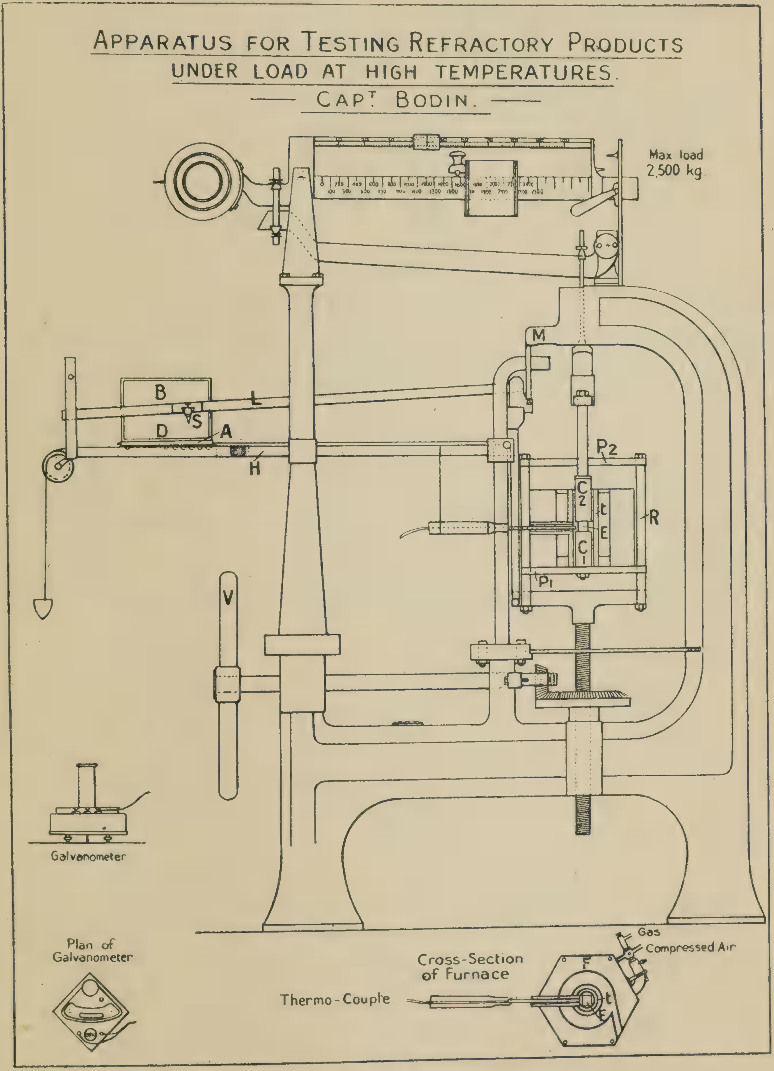


FIG. 5.

that here the same rule applies, *i. e.*, some of the bricks that we have difficulty getting up to 1600 °C might stand more at higher temperatures.

Mr. Greaves-Walker:—These curves would seem to show that that is the case, but the difficulty they have had in hot blast stoves, for instance, has been eliminated by finding a brick that had strength enough at its weakest point to carry the load until they passed on up to the temperature at which the stove was operating.

Mr. Hull:—It just occurs to me that if this is true with the special refractories we have been testing it would be feasible to reverse the furnace and heat it from the top down instead of from the bottom up.

Dr. Harvey:—This is exceedingly interesting, if true. It might give the explanation for something we so often find in clay brick. We find kiln marked brick that have not had a load on them to cause anything like sufficient compression or that apparently have been subjected to the maximum temperature of the kiln. This raises the question of carrying the brick past the critical temperature at great speed. It may be that by putting the heat to it just as fast as you can when you are passing the critical point for the clay in question, it will eliminate kiln marking of the brick. We know, for instance, in clay brick that the time factor is just as important as temperature.

Mr. Ross:—Are you sure your brick was dry and your kiln was dry in the kiln marked brick?

Dr. Harvey:—You will find kiln marked brick under every condition you can conceive.

COMPARATIVE TESTS OF ENGLISH AND DOMESTIC WHITINGS[1]

By A. E. Williams and B. J. Woods

ABSTRACT

A knowledge of the properties of American whiting as compared with those imported from England is of importance to producers of the American material as well as to manufacturers of products in which whiting may be used.

Twenty-two samples of domestic and foreign whiting have been submitted to examination and tested as follows: (1) visual examination, (2) microscopic examination, (3) determination of fineness of grain by three methods, (4) partial chemical analysis, (5) effect of the different whitings on the softening point of ceramic cone mixtures, and (6) effect on rate of vitrification of porcelain bodies.

The results indicate that although the English whitings contain considerably more fine material of a colloidal nature, the American whitings appear to be sufficiently fine grained for all ceramic purposes.

This extreme fineness may play a part in assisting in the flotation of the frit in glazes containing a low percentage of clay, but apparently has no effect in the fluxing point of ceramic glaze or body mixtures.

Sufficient data has been obtained to permit of the preparation of tentative specifications for whiting for ceramic purposes and the main requirements of such a material are given.

Introduction

Interest in the production of whiting in the United States together with the fact that there is considerable prejudice among the potters in favor of using English whiting, makes an investigation of the various properties of these two classes of whitings desirable. The problem of preparing specifications for potters' whiting has also been considered by the "Interdepartmental Conference on Chemical Lime," which conference has prepared specifications for lime for various other industrial uses. Specifications could not be prepared without a study of the comparative properties of the foreign and domestic products, as much is claimed for the physical condition of the material found in the English chalk deposits.

Information regarding the requirements of the potter is very necessary to the producer of this material or any other. There has been more or less justified complaint of domestic pottery materials by the potters of the United States. The producer did not know or realize the care which should be given the preparation of potters' material in order that the product might be consistent in quality from month to month and year to year. This lack of knowledge on the part of the producer has caused him to ship domestic materials to the potter which were not properly and uniformly prepared and therefore have caused considerable trouble and developed prejudice that is very hard to overcome.

Quality of American Limestones.—American limestones occur in several districts as a very pure calcium carbonate rock, so that so far as purity is concerned domestic whitings equal to those available anywhere can be produced. It is only necessary to put this rock in the physical condition considered satisfactory to the potter.

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[1] Published by permission of the Director of the Bureau of Standards, Department of Commerce.

Samples of Whiting Examined.—In order to proceed with this work samples of whiting actually being used were gathered from potters and dealers with a request for as much information as possible regarding their origin. Twenty-two samples have thus been selected for test, representing foreign and domestic products. These are listed with their sources in Table I.

TABLE I

SHOWING KIND AND SOURCE OF WHITING

No.	
1	Lump or ordinary whiting—Meeching Chalk Quarries, Newhaven, Sussex, England.
2	Finest ground Paris white—Meeching Chalk Quarries, Newhaven, Sussex, England.
3	Whiting—prepared in U. S. from crude chalk imported from England.
4	Paris white—prepared in U. S. from Cliffstone Rock imported from England.
5	Paris white—obtained from dealer in U. S.; imported as Cliffstone Paris white.
6	Whiting—obtained from potter in U. S.; made from imported English chalk.
7	Paris white—obtained from potter in U. S. who specifies English Cliffstone Paris whiting.
8	Paris white—obtained from potter in U. S.; bought as Paris white.
9	Paris white—obtained from potter in U. S. who specifies imported Paris white.
10	Paris white—obtained from dealer in U. S.; made from English Cliffstone Rock.
11	Domestic whiting—obtained from dealer in U. S.
12	Domestic whiting—obtained from dealer in U. S.; ground domestic limestone.
13	Domestic whiting—obtained from tile manufacturer.
14	Domestic whiting—obtained from potter.
15	Domestic whiting—obtained from dealer of ground limestone.
16	Domestic whiting—obtained from sanitary ware manufacturer.
17	Domestic whiting—obtained from tile manufacturer.
18	Domestic whiting—obtained from pottery manufacturer.
19	Domestic whiting—obtained from dealer in U. S.; coarse grade ground limestone.
20	Domestic whiting—obtained from producer in U. S.; ground calcite rock.
21	Domestic Paris white—obtained from dealer in U. S. Raw material not known.
22	Domestic whiting—obtained from dealer in U. S.; chemically precipitated whiting.

The examinations and tests made on these whitings were as follows: (1) visual examination; (2) microscopic examination; (3) determination of fineness of grain by the following methods: (*a*) rate of settling in water, (*b*) air separation by use of the Pearson air separator, (*c*) screening; (4) partial chemical composition; (5) effect of whitings on softening point of ceramic cone mixtures; and (6) effect on rate of vitrification of porcelain bodies.

Visual Examination.—Comparing the appearance of English and American whitings, considerable difference in color is observed in some instances, the domestic product being very much whiter than the English. The English whiting has a dirty gray-white color in comparison with a good white powder of any kind, and also shows a tendency to segregate into little pellets rather than to flow as a fine powder. Some domestic whitings also show this same tendency, and exhibit shades of white that are intermediate between the English product and the whitest domestic material. The color of these powders is greatly affected by fineness of grain and this factor may be the principal cause of such color differences. In the gray samples showing a tendency to be lumpy no black specks were visible; the white samples, however, all showed visible black specks. These were identified in one case as particles of coke, being very soft and friable. The gray color may serve to mask the visibility of these specks.

Microscopic Examination.—Microscopic examination of these samples brings out several distinguishing features between imported and domestic whitings. The imported whitings are known to come from a soft marine formation, and to consist of rather fragile shell material. Under the microscope these whitings show as a mass of small fragmentary particles with occasional circular or semi-circular particles distinguishable as shells. Domestic whitings appear as sharper-edged particles without the occasional shells.

The imported whitings show a considerable amount of Brownian movement in the ultra-microscope, whereas domestic whitings do not show this phenomenon. There is, therefore, a difference in fineness shown by the smallest particles of the two classes. No visible difference was found between the washed product made from cliffstone rock and that made from chalk. The unwashed rock or chalk does not show any Brownian movement when simply broken up in a mortar and examined. Chemically precipitated whitings seem to be rather fine grained but quite uniform in size and show none of the large fragments found in the ground rock whitings.

Report of Microscopic Examination

Microscopic examinations were made by W. H. Fay, of the Bureau of Soils in the Department of Agriculture, who examined them especially for colloidal material; his detailed report is given herewith:

> The twelve samples of whiting submitted for microscopic and ultra-microscopic examination gave the following results: Nos. 12, 16, 21, 20 and 11 all show distinctly crystalline materials with little tendency to aggregate. The size of the particles varies in each sample over an extremely wide range. All the other samples, Nos. 15, 2, 22, 3 and 4, show very small grained particles all of a fairly uniform size. Nos. 12, 15, 16, 21, 22, 20 and 11 show practically no colloidal material under the ultra-microscope. Nos. 2, 3, and 4 all show some materials of colloidal dimensions though in no case does this small material constitute any very considerable percentage of the whole sample.
>
> In addition to the foregoing résumé we are sending you the detailed report of the examination of each sample as follows:
>
> No. 12. Under petrographic microscope—grain-size very varied, but practically all of the visible particles are discrete crystals showing no marked tendency to aggregate. Distinctly crystalline. Very small amount of quartz, etc. Under ultra-microscope, practically no colloidal material visible.

No. 15. Under petrographic microscope—grains distinctly crystalline between crossed nicols. Grain-size very small and uniform, with a very strong tendency to aggregate. Under ultra-microscope, practically no colloidal material visible.

No. 16. Under petrographic microscope—distinctly crystalline. Grain-size very varied but not quite so extreme as under No. 12. No marked tendency to aggregate. Under ultra-microscope, practically no colloidal material visible.

No. 21. Under petrographic microscope—distinctly crystalline. Grain-size varied but apparently less so than with No. 16. Some tendency towards aggregates. Smaller particles seem more abundant proportionally than in No. 12 and No. 16. Under ultra-microscope, practically no colloidal material visible.

No. 2. Under petrographic microscope—distinctly crystalline. Grain-size very small and uniform with a strong tendency to aggregate, though this tendency is apparently less than in No. 15, neither are the grains quite so small as a rule.

Under ultra-microscope, material fine in size showing considerable Brownian movement, although the actual percentage amount of particles of colloidal size does not appear very great.

No. 22. Under petrographic microscope—distinctly crystalline. Grain-size very small and uniform, with a very strong tendency to aggregate. Under ultra-microscope, material of very fine size, showing practically no Brownian movement.

No. 3. Under petrographic microscope—distinctly crystalline. Grain-size very small and uniform, with a very strong tendency to aggregate. Under ultra-microscope, about as under No. 2.

No. 4. Under petrographic microscope—distinctly crystalline. Grain-size small, but still somewhat larger than in No. 3, and usually uniform, although there are very marked sporadic exceptions. There is a tendency to aggregate but it is very much less than in No. 3. Under ultra-microscope, some Brownian movement, but apparently less than in Nos. 2 and 3.

No. 20. Ground Calcite—under petrographic microscope—distinctly crystalline. Grain-size very unequal, with the mass of smaller particles distinctly larger than in No. 3, for example. Practically no tendency to aggregate. Under ultra-microscope, practically no colloidal material visible.

No. 11. Domestic Paris White—under petrographic microscope—in all respects, about as under No. 20. Under ultra-microscope, practically no colloidal material visible.

Crude English Chalk—material lumpy, therefore necessitating grinding in agate mortar before microscopic examination. Under petrographic microscope about as under No. 3. Under ultra-microscope, ground material shows practically no Brownian movement.

Crude English Cliffstone, Paris White—material lumpy, therefore necessitating grinding in agate mortar before microscopic examination. Under petrographic microscope, about as under No. 4. Under ultra-microscope, ground material shows practically no Brownian movement.

Relative Fineness of Grain

The physical structure, especially the fineness of the material, is considered by many to be the chief distinguishing feature in favor of the use of English whiting. There is no doubt that there is a great difference between a product in which the grains are made up of fragile material and a product produced by grinding hard rock. The material composing the chalk cliffs of England is fragile shells or fragments of shells, very easily crushed to a powder and the resulting particles have feather-like edges, rather than sharp, angular edges.

The No. 140 and No. 200 screen sizes, U. S. Standard, were determined by wet screening, using a 10-gram sample on a 3-inch screen and a small stream of water practically without pressure. Washing was continued for ten minutes.

Various methods were tried to determine the grading in size of the particles finer than those passing 200-mesh screen, such as determining the rate of settling by use of the Odén balance, or by determining the change in turbidity with time. However, these did not give what were considered valuable results because the agglomeration of the particles caused settling more rapidly than the true fineness would indicate. Attempts to deflocculate were not successful, thus a true separation of the material into its ultimate particles was not possible. A method[1] of air separation that is being developed by the Cement Section of this Bureau gave probably the most accurate separation of particles finer than 0.05 mm. Grades designated as Nos. 01, 1, 2 and 3, approximating what might be called 2000-, 1000-, 500-, and 350-mesh sizes were so separated. The maximum size of particles for each of these grades is given, being an average of the width of fifty particles collected on a microscopic slide in the dust collector.

Comparing the fineness of whitings (Table II) from these results, there is no practical difference evident for sizes equivalent to 200-, 350-, and 500-mesh sizes. Only two samples, Nos. 16 and 19, show less than 85% of the material finer than the equivalent of 500-mesh (No. 2 size on air analyzer) and one of these, No. 19, is a coarse-grained product, not marketed as a whiting but simply as ground limestone. These same samples and one other (No. 12) are the only samples leaving a residue of more than 2% on a No. 200 screen. Important differences in fineness are only evident in the finest separation made (size 0.01 on the air analyzer passing about a 2000-mesh screen). The whitings made from English chalk or cliffstone show 68% or more material finer than this size, while no domestic product has more than 65%, and the average of 11 samples, not including No. 19, is only 46.9%.

Another simple method of separation was tried which consisted in shaking $2^1/_2$ grams of whiting in water in a 250-cc. graduated cylinder filled to the 250-cc. mark, and noting the time when visible motion of the particles ceased entirely, and when the turbidity had been reduced sufficiently to make a red line at the 150-cc. mark visible through the liquid. In clear skylight without sun satisfactory check readings were obtained. The results (Table II) show a definite distinction between the product made

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[1] J. C. Pearson and W. H. Sligh, "An Air Analyzer for Determining Fineness of Cement," U. S. Bur. Standards, *Tech. Paper* **48.**

TABLE II

TABLE SHOWING SIZE OF GRAIN IN ENGLISH AND DOMESTIC WHITINGS

	Mechanical analyses Pearson air separator								Screen analysis			Rate of settling of whiting in distilled water	
	Air analyzer Per cent blown off				Microscope's measurements								
	No. .01	No. 1	No. 2	No. 3	No. .01	No. 1	No. 2	No. 3	Per cent residue on No. 140	Per cent residue on No. 200	Per cent passing No. 200	Time of visibility of red line at 100 cc. from top	Time when visible motion of particles ceased
						English Whiting							
1	87.4	97.7							0.0	0.2	99.8	25 minutes	27 minutes
2	87.5	97.8							0.1	0.1	99.8	Not visible in 30 minutes	30 minutes
3									0.2	0.4	99.4		
4									0.3	1.4	99.8		
5	74.6	86.7	95.4		0.0128	0.0213	0.0400		0.2	1.1	98.7	Not visible in 30 minutes	24 minutes
6	82.7	92.2			0.0132	0.0251			0.0	0.5	99.5	Not visible in 30 minutes	24 minutes
7	68.8	81.2	91.6		0.0135	0.0257	0.0420		0.5	1.4	98.1	Not visible in 30 minutes	24 minutes
8	75.0	84.3	93.2		0.0117	0.0225	0.0403		0.3	1.0	98.7	23 minutes	30 minutes
9									0.0	0.1	99.9	23 minutes	27 minutes
10									0.0	0.0	100.0	25 minutes	20 minutes
						Domestic Whiting							
11	48.0	70.4	99.7		0.0125	0.0217			0.0	0.0	100.0	5 minutes	11 minutes
12	52.6	69.9	85.5		0.0112	0.0242	0.0418		1.8	2.2	96.0	25 minutes	30 minutes
13	49.6	73.3	95.4		0.0115	0.0208	0.0435		0.1	0.3	99.6	16 minutes	20 minutes
14	56.8	70.2	88.6	95.8	0.0120	0.0218	0.0362	0.0501	0.0	0.1	99.9	12 minutes	25 minutes
15	47.6	96.7			0.0152	0.0220			0.2	0.2	99.6	10 minutes	15 minutes
16	28.4	41.9	70.4	83.2	0.0115	0.0210	0.0384	0.0610	5.5	2.8	91.7	10 minutes	15 minutes
17	36.0	63.4	96.8		0.0118	0.0207	0.0407		0.0	0.0	100.0	5 minutes	15 minutes
18	36.2	96.6			0.0130	0.0240			1.5	0.5	98.5	4 minutes	13 minutes
19	5.7	13.0	35.4	45.6	0.0124	0.0221	0.0389	0.0549	45.2	11.3	43.5		
20	53.8	74.4	96.0		0.0125	0.0211	0.0414		0.0	0.0	100.0	7 minutes	18 minutes
21	65.2	83.0	98.5		0.107	0.0217			0.0	0.0	100.0	8 minutes	18 minutes
22	41.7	96.8			0.0140	0.0237			0.2	0.7	99.1	7 minutes	19 minutes

from English chalk and American ground materials, such that at present this may be used as a means of identification of the English product. The time when visible motion ceases is 24 minutes or longer for the English whiting, whereas but two of the domestic samples required so much time. The time required for settling sufficiently to form a clear liquid at the top was 23 minutes or more for the English whitings, whereas but one domestic sample required more than 16 minutes.

Evidence that English whitings contain a considerable percentage of material much finer than domestic ground products has thus been shown microscopically, by mechanical air separation, and by settling in water. The percentages of coarser particles such as 140-, 200-, and 350-screen sizes are practically the same and consequently there is no difference in the possibilities of trouble resulting from occasional coarse particles. Whether the amount of extremely fine material makes any practical difference, except where flotation of a slip is desired, is doubtful; at least no evidence of such differences was shown in any of the tests made in this work.

Chemical Composition.—Comparison of domestic and English whitings on a basis of chemical composition shows but little difference in their qualities, so far as iron content and insoluble residue are concerned. Considering the results shown in Table III the iron content is generally higher for domestic samples but in most cases so low as to be of no consequence. The insoluble residue is about the same for English and domestic whiting except for two samples, Nos. 16 and 19, the latter being a coarsely ground limestone rather than a whiting.

TABLE III

RESULTS OF ANALYSIS OF ENGLISH AND DOMESTIC WHITING

No.	Per cent Fe_2O_3	Per cent insol. residue after boiling in HCL	No.	Per cent Fe_2O_3	Per cent insol. residue after boiling in HCL
1	0.084	1.61	12	0.243	3.51
2	.111	1.74	13	.243	2.65
3	.110	3.25	14	.150	1.61
4	.130	2.18	15	.248	1.16
5	.062	1.69	16	.315	7.82
6	.101	2.25	17	.152	1.64
7	.089	1.63	18	.158	1.85
8	.098	2.30	19	.231	5.49
9	.124	1.34	20	.167	1.32
10	.124	1.34	21	.172	3.23
11	.077	1.47	22	.201	1.27

Qualitative analysis for sulphur rarely gives any positive results unless the solution is allowed to stand over 12 hours, and then the quantity is only evident as a slight turbidity. It would appear that sulphur present in any form in so small an amount that a precipitate will not appear within a few minutes after barium chloride is added to the hot solution may be regarded as negligible.

It is generally recognized that whiting is a practically pure calcium carbonate. The English product contains no magnesium, but domestic limestones may contain one to two per cent. Small percentages of magnesium cannot be considered as harmful to a whiting for pottery purposes.

Specific Gravity of Whiting.—Density determinations were made on a variety of samples illustrating the general types of raw material used. These are shown in the following table (IV) and indicate that except for the precipitated product the densities are nearly identical.

TABLE IV

SHOWING SPECIFIC GRAVITY OF WHITING SAMPLES

Sample number	Source of material	Specific gravity
3	English Chalk	2.721
4	English Cliffstone Rock	2.721
12	Ground Limestone	2.733
13	Ground Limestone	2.727
20	Ground Calcite Rock	2.729
22	Chemically Precipitated	2.587

Putty-making Properties.—A property peculiar to English whiting, which property products ground from American raw materials or the chemically precipitated sample do not show to such an extent, is the ability to mix with linseed oil to make a satisfactory putty. English whitings when mixed with 14% to 15% of oil produce a fairly plastic putty having a fair amount of cohesion. American samples require from 14 to 34.5% of oil and their value as a putty decreases with the amount of oil required, both because they do not have proper cohesion and because they require too much oil. Whitings requiring more than 18 per cent of oil to produce proper working plasticity do not make good putties. Table V shows a comparison of the oil absorption and putty-making properties of whitings tested.

TABLE V

TABLE SHOWING PERCENTAGE OF STANDARD LINSEED OIL REQUIRED TO BRING WHITING TO PROPER CONSISTENCY TO WORK AS PUTTY AND THE PERCENTAGE REQUIRED TO DILUTE IT BEYOND A WORKING CONSISTENCY. ALSO THE RELATIVE WORKING QUALITIES

No.	Per cent oil for proper consistency	Per cent oil making putty too fluid	Quality of putty
1	15.0	15.5	Good
2	15.1	15.6	Good
3	....	....	....
4	....	....	....
5	15.1	15.9	Good
6	15.2	16.0	Good

7	14.3	15.1	Good
8	13.9	14.3	Good
9	15.5	16.1	Good
10	15.0	15.7	Good
11	14.7	16.3	Short
12	13.3	13.9	Good
13	18.0	18.8	Fair
14	15.0	15.6	Good
15	28.7	30.4	Short
16	14.9	16.2	Short
17	22.3	23.4	Short
18	30.0	32.9	Short
19	....	....	....
20	....	....	....
21	17.0	17.6	Good
22	33.0	34.0	Very short

If this property were one due to extreme fineness of grain alone it might serve us as a distinguishing feature between English and domestic whitings. It has been suggested however that variety of sizes of grain might be the controlling factor causing adhesion and low oil absorption rather than fine material and that mixing material ground in two or more different ways might produce a satisfactory putty whiting.

Use of Whitings in Pottery Bodies and Glazes.—Experience has shown that whitings containing relatively coarse grains produce unsatisfactory results. The maximum grain size which may be included without detriment has not been determined. While it seems obvious that extreme fineness is desirable in whitings for both bodies and glazes, it also seems probable that there is a limit in fineness beyond which further reduction in the size of particles would have no appreciable effect. Since it was impossible to conclude, from the information available, whether the whitings produced from English stone and containing a considerable proportion of material which is finer than the finest portion of the domestic whitings would give better practical results than the domestic material, a series of trials was made to determine the relative behavior of the two types.

In order to detect, if possible, any difference in the behavior of these whitings as far as body mixtures are concerned, cones approximating cone 4 in composition were made in which the brand of whiting was the only variable. The composition of the cones were: Maine feldspar, 42.1%; flint 27.2%; whiting 17.6% and North Carolina kaolin 13.1%. The mixture was ground dry in a ball mill except for the whiting content, which was later mixed with the proper proportion of the ground body and mixed thoroughly in a mortar.

Two burns were made, the cones on four plaques being placed in the center of a muffle with standard cones in the center of each plaque. In one burn the temperature was increased rapidly as the melting point of the cones was approached, the rate being 100° per hour from 1100° to 1200°C. In the other burn the temperature was increased not more than 20° per hour from 1000° to the finish, although the 20° increases were occasionally not uniform, the rise in temperature being obtained during the first 15 minutes of the hour. The uniformity of temperature in the muffle is best judged by the fact that standard cones of the same number in different locations in the furnace went down practically together on the rapid burn, and within an interval of 20 minutes, during which there was a temperature increase of 15° in the long burn. In both burns sample No. 19, containing a very coarse ground limestone as shown by the screen tests, did not fuse readily but remained standing at a temperature of 20° higher one hour after all others had fused. In the rapid burn all cones softened within a temperature interval of 10° beginning at 1145°C except the standard cones which started to deform just previous to the test cones. In the slow burn the standard cones went down between 1100° and 1115°C over a period of 15 minutes. The test cones deformed beginning at 1120° and extending over a temperature range of 35° and a period of 1 hour and 45 minutes. Fig. 1 is a time-temperature curve on which is indicated the fusing points of the various cones. It will be noted that there is no consistent difference between English and American whitings, there being as great a variation in the English product as in the American whitings.

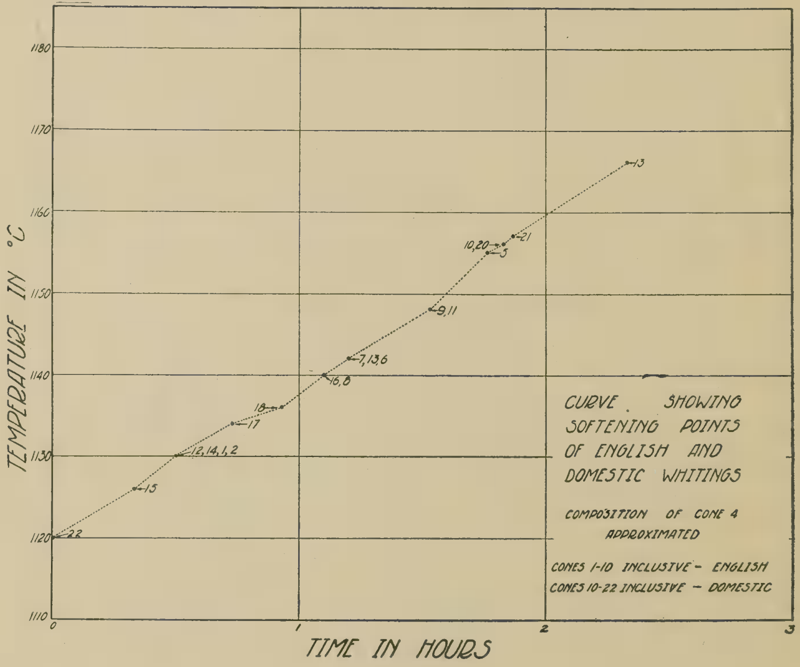
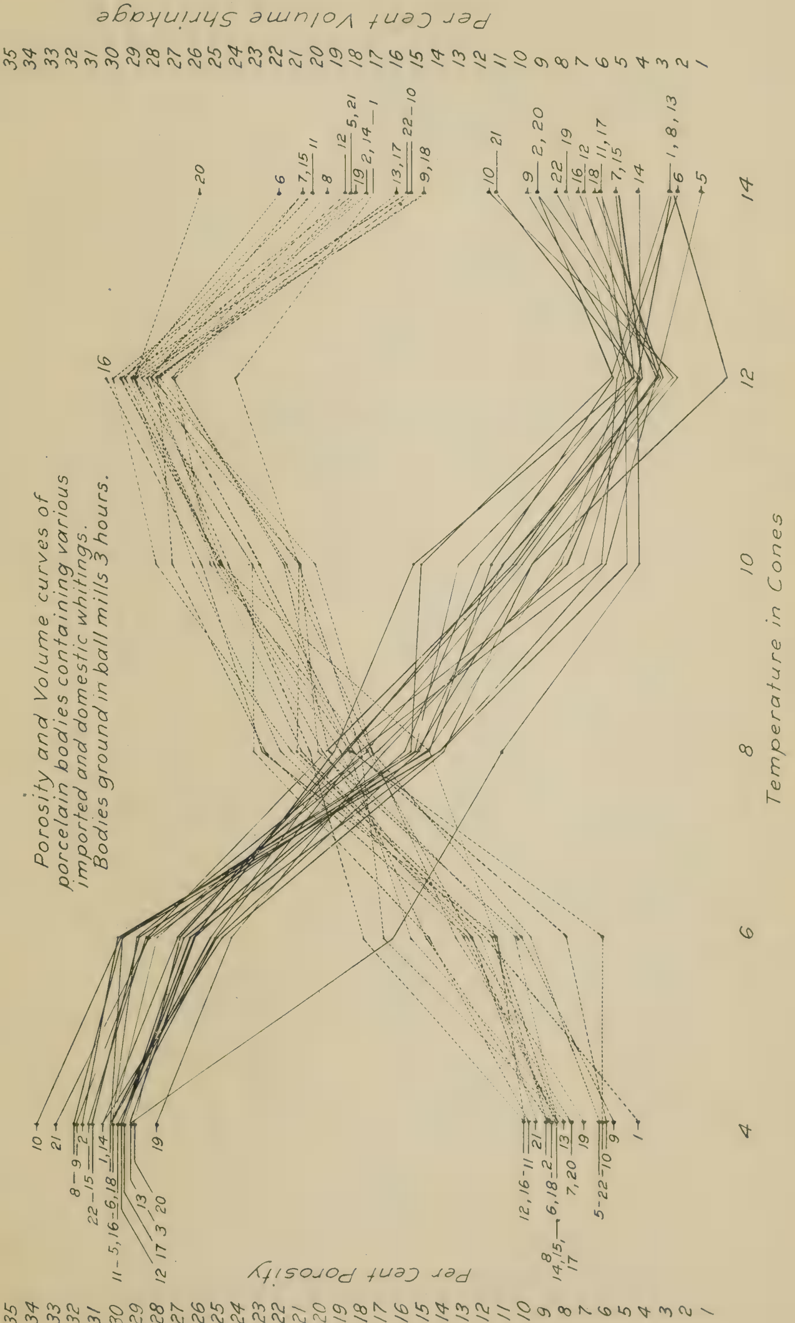


FIG. 1.


Porosity and Volume curves of porcelain bodies containing various imported and domestic whitings. Bodies ground in ball mills 3 hours.
Per Cent Volume Shrinkage
Per Cent Porosity
Temperature in Cones
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
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1, 8, 13
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21
8 - 9
2
22 - 15
1, 14
11 - 5, 16 - 6, 18
12 17 3 20
13
19
12, 16 - 11
21
8
14, 15, 17
6, 18 - 2
7, 20
13
19
5 - 22 - 10
9
1

Fig. 2.

Comparison of Whitings Used in Porcelain Bodies.—In addition to determining the effect of various whitings on the softening point of a mixture, porcelain bodies, in which the only variable was the whiting, were also made, burned and tested in the usual manner.

The composition of the body used was:

Tenn. ball clay No. 5	5.7%
Georgia kaolin	9.5%
Florida kaolin	9.5%
North Carolina kaolin	9.5%
Delaware kaolin	9.5%
Potash feldspar	17.7%
Flint	36.6%
Whiting	2.0%

One set of bodies was made in which the materials were ground in a ball mill for three hours and screened over 120-mesh lawn. Samples of these bodies were burned to cones 4, 6, 8, 10, 12, and 14, and the porosity and volume changes determined. These results are shown graphically on Fig. 2 and offer no evidence of any consistent difference between the English and domestic product. Grinding of these bodies, however, might easily have served to eliminate many differences which the whitings might have produced. This is especially true of the very coarsely ground limestone No. 19. A duplicate set of bodies was therefore made with the exception of introducing the whiting without any grinding.

Two burns were made of samples prepared from these bodies containing the unground whitings. Although the porosities and volume changes do not check from burn to burn because of furnace conditions, examination of Tables VIII and IX shows no consistent difference evident between the two classes of whiting except that the very coarse grained sample (No. 19) did not give a large change in volume between cones 12 and 14 as it did when ground. These samples were also full of glassy spots where the coarse particles of whiting had fused with the body.

The results of the various physical and chemical tests seem to indicate that there are no pronounced differences in the action of English and domestic whitings in porcelain bodies or in affecting softening point. There is a difference in fineness of grain which may affect the usefulness of the whiting in the case of raw glaze or when using the whiting in place of clay to float the glaze.

There are, however, important factors which can give trouble and which are likely to occur with a domestic product if the producer does not exert the proper care in preparation. These are (1) lack of uniformity of the product from shipment to shipment; (2) freedom from iron minerals which is necessary to avoid black specks in the ware. Grinding and washing of whiting should remove the possibility of trouble from this source as the

TABLE VIII
POROSITY OF BODIES AT CONES 12 AND 14

No.	Ground bodies Cone 12	Ground bodies Cone 14	1st burn Unground bodies Cone 12	1st burn Unground bodies Cone 14	2nd burn Unground bodies Cone 12	2nd burn Unground bodies Cone 14
			English Whiting			
1	0.0	2.7	0.15	0.40	0.17	0.28
2	5.6	9.2	.10	.60	.61	9.04
3	...	....	.10	.50	.33	9.25
4	...	....	....	.50	2.25	11.42
5	3.5	1.2	.15	.30	5.33	13.88
6	4.4	2.4	2.50	4.40	0.65	8.8
7	4.6	5.6	.15	.10	.15	8.8
8	5.7	2.8	1.40	.25	.19	10.8
9	4.3	9.8	.25	.20	.22	8.4
10	2.5	11.7	.04	1.00	.17	8.60
			Domestic Whiting			
11	3.4	6.3	0.70	0.0	0.18	6.2
12	4.7	7.0	.30	.1	.42	5.5
13	4.2	2.9	1.6	2.6	.45	4.5
14	4.3	4.5	2.9	....	.31	7.6
15	4.2	5.5	0.0	2.8	.62	9.9
16	3.5	7.4	2.0	1.0	.42	7.4
17	5.1	6.3	0.15	2.0	.24	8.6
18	3.2	6.6	.10	2.9	.16	6.4
19	5.1	9.0	5.40	2.5	1.3	1.7
20	2.7	9.5	.26	....	.11	9.9
21	4.4	11.4	.40	0.10	.35	.42
22	3.3	8.5	.35	6.0	.10	12.1

TABLE IX
VOLUME SHRINKAGES AT CONES 12 AND 14 COMPARING GROUND AND UNGROUND BODIES

No.	Ground bodies Cone 12 1250°C	Ground bodies Cone 14 1400°C	Unground bodies 1st burn Cone 12 1240°C	Unground bodies 1st burn Cone 14 1400°C	Unground bodies 2nd burn Cone 12 1315°C	Unground bodies 2nd burn Cone 14 1340°C
			English Whiting			
1	29.4	17.0	32.8	28.5	31.2	26.8
2	28.8	17.6	32.7	28.7	29.2	23.2
3	....	....	28.7	25.4	31.4	25.3
4	....	....	28.5	24.9	32.0	25.8
5	27.0	18.3	27.9	22.8	25.3	23.2
6	29.1	21.8	27.2	25.2	31.2	20.0
7	28.1	20.8	29.9	28.0	30.5	21.0
8	27.0	19.5	27.9	26.6	28.5	23.0
9	28.5	14.8	32.2	24.5	31.0	22.2
10	27.8	15.4	32.8	28.5	27.7	21.8
			Domestic Whiting			
11	28.9	20.2	27.5	28.4	31.2	25.7
12	28.2	18.6	29.2	29.4	26.3	24.1
13	27.6	16.2	30.3	26.6	28.5	25.3
14	28.1	17.5	23.5	25.4	29.2	23.5

TABLE IX (*Continued*)

No.	Ground bodies Cone 12 1250°C	Ground bodies Cone 14 1400°C	Unground bodies 1st burn Cone 12 1240°C	Unground bodies 1st burn Cone 14 1400°C	Unground bodies 2nd burn Cone 12 1315°C	Unground bodies 2nd burn Cone 14 1340°C
			English Whiting			
15	29.3	20.6	29.8	24.0	29.3	22.7
16	30.2	....	30.9	18.4	30.1	21.5
17	27.7	16.4	29.2	26.0	24.7	25.7
18	28.8	14.7	28.9	29.2	30.5	22.8
19	26.9	18.2	28.0	19.6	29.3	28.8
20	28.8	25.7	30.1	20.5	29.5	24.2
21	29.9	17.0	31.4	25.4	24.5	26.2
22	29.5	15.6	32.0	29.5	22.8	25.7

heavy particles can be settled out with the coarse material. (3) The last factor is freedom from particles of gypsum ($CaSO_4 2H_2O$) because of the sulphur it introduces. Sulphur is given as the chief cause of scumming found after the glost burn, and occasional cases of scumming have been attributed to the whiting. Thus minerals containing sulphur are prohibitive, and can be eliminated by selecting the stone for grinding. Domestic whiting suitable for ceramic uses can be produced and the success or failure of a domestic product depends almost entirely on the care of the producer.

As a result of the various comparative tests made, a tentative specification for whiting has been prepared by the "Interdepartmental Conference on Chemical Lime."

The important qualifications specified are repeated with the following requirements:

(1) *Quality.*—Whiting shall be uniform in quality (from shipment to shipment), both as to fineness of grain and composition, each shipment meeting the requirements given below. It shall be manufactured from the purest limestones available, and shall be free from pyrites, iron-bearing silicates, metallic iron, and gypsum.

(2) *Composition.*—Whiting shall have the following limitations in composition:

Material	Total carbonates	$CaCO_3$	$MgCO_3$	Fe_2O_3
Maximum	....	....	2%	0.2%
Minimum	97%	95%	...	.....

A qualitative test shall indicate the absence of sulphur.

(3) *Fineness.*—Screening samples by washing for ten minutes with a stream of water of low pressure shall not leave a residue of more than 1% on a No. 140 screen (or more than 2% on a No. 200 screen), and at least 98% of the material shall pass a No. 200 screen. Whiting shall also be so

fine that a separation made by a Pearson[1] air separator will show at least 85% of the material finer than 0.02 mm. and at least 48% finer than 0.01 mm.

As an alternative to the Pearson air separator method the following method (not so desirable) may be used: $2^1/_2$ grams of the material shall be shaken for ten minutes in a 250-cc. cylindrical graduate with 250 cc. of distilled water. On allowing to settle it shall require not less than 20 minutes for visible settling to cease when the cylinder is viewed in reflected light, using clear north skylight for illumination.

U. S. Bureau of Standards
Washington, D. C.

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[1] J. C. Pearson and W. H. Sligh, *loc. cit.*

THE MEASUREMENT OF THE PLASTICITY OF CLAY SLIPS[1,2]

By Robert E. Wilson and F. P. Hall

ABSTRACT

1. The paper emphasizes the great need of a quantitative measure of the physical properties commonly included in the term "plasticity" of clays and clay slips. Various indirect methods previously suggested are likely to lead to erroneous conclusions, while measurement of the flow or apparent viscosity of clay slips made up with a constant amount of water is shown to give misleading results.

2. The work described in this paper is preliminary in nature and has been confined to a study of the properties of clay-water mixtures in the casting rather than in the molding range. In the light of these results it is recommended that, instead of the vague term plasticity, the properties of a given clay, at least for casting purposes, be expressed in terms of (*a*) the water content required to give proper working consistency, and (*b*) the resistance of the resulting slip to small deforming forces (such as gravity). Specifically, use is made of a modified Bingham plastometer, and the figures reported are (*a*) the amount of water required to give a slip of a specified mobility, and (*b*) the yield value of the slip thus obtained.

3. The method is shown to be capable of giving quantitative figures for the yield values at constant mobility which correspond well with the customary qualitative ideas as to the plasticity of clays. The amount of water required to give constant mobility varies to a surprising extent, and does not appear to bear any definite relationship to the usual classifications of more or less plastic clays. It probably does parallel fairly well the shrinkage on drying.

4. Small amounts of acid or alkali are shown to have a negligible effect on the mobility of a clay slip, but a very large effect on the yield value, the variations being greater than the difference between a non-plastic kaolin and a highly plastic ball clay. This brings out the necessity, and indeed the potential value, of carefully controlling the hydrogen-ion content of the water used in making the slips.

5. Some preliminary data are given on the effect of additions of flint and similar non-plastic materials to clay slips.

6. It is recommended that an attempt be made to agree upon standard dimensions for the capillary and the desirable mobility for various purposes, and that the plastometer then be used as a standard method of test in the ceramic industry.

Introduction

From a practical standpoint, "plasticity" is one of the most important properties or rather combination of properties possessed by any clay. Different clays are known to vary greatly in plasticity. Furthermore, in practical clay working, substances are frequently added for the express purpose of increasing or decreasing the plasticity of the final mix.

In spite of these facts, however, no unit of plasticity has ever been defined, and there is no generally accepted method of measuring or comparing

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[1] Published as *Contribution*, No. **63** from the Research Laboratory of Applied Chemistry, Massachusetts Institute of Technology. Simultaneous publication by courtesy of Dr. H. E. Howe, Editor of *The Journal of Industrial and Engineering Chemistry.*

[2] Presented before the division of Physical and Inorganic Chemistry at the New York meeting of the American Chemical Society, Sept. 1921.

the plasticity of different clays. To be sure, many indirect methods have been suggested for its quantitative measurement. For example, the amount of adsorption of malachite green, the adsorption of alkali from various salt solutions, the strength of clay bodies after drying, the amount of water required to bring the clay to proper consistency, etc. These factors are undoubtedly in some way related to plasticity, being common results of similar causes, the main factors probably being the fineness of subdivision of the ultimate particles and their affinity for water. It is nevertheless true that in many cases clays may possess high adsorptive power for dyes, etc. (*e. g.*, fuller's earth) and yet have low plasticity. Such indirect methods of measuring plasticity have therefore not met with any general acceptance, and ultimate reliance is still placed on empirical tests by experienced clay workers, although even such individuals do not consistently agree with one another.[1]

It is obvious that the ultimate solution of the problem must involve the measurement of the physical properties of a clay slip with a water content approximately correct for practical use. Some efforts have been made in this direction by determining the flow of a clay slip through an orifice or by the use of paddle wheel viscometers, but these have not given satisfaction, partly because of the difficulty in determining just how much water should be added before making the test, and partly because it is not possible to measure the true viscosity of clay slips, as is evidenced by the subsequent discussion.

The most promising possibility for making the desired measurement appears to be the use of a device such as the plastometer, recently developed by Prof. E. C. Bingham.[2] Prof. Bingham has shown that when a plastic substance flows through a capillary of constant dimensions, the amount of flow is not directly proportional to the pressure used, as in the case of viscous liquids, but departs therefrom by giving abnormally low rates of flow for low pressures and then increasing more rapidly at higher pressures. The two different types of flow curve are illustrated very clearly in Fig. 1, which presents results for a very viscous oil and for a clay slip, in the capillary used in the work described hereinafter.

It is Prof. Bingham's belief that the rounding off in the curve in the lower portion may be due to slippage or seepage, and that the laws of plastic flow may for all practical purposes be represented by a straight line intersecting the abscissa axis at some point to the right of the origin. The distance to the point of intersection, in proper units, is defined as the yield point and the slope of the line is a measure of the mobility of the suspension. It is not the purpose of this paper to discuss the rather involved points with regard to the cause and equation for the lower curved portion of this line, nor the questions which have arisen as to the degree of dependence of the results on the size of the capillary used. Both these factors, while of considerable theoretical interest, may for practical purposes be eliminated by agreement upon a standard capillary and by working with pressures which are sufficiently great, just as has been done in practical viscometry by using the Saybolt instrument.

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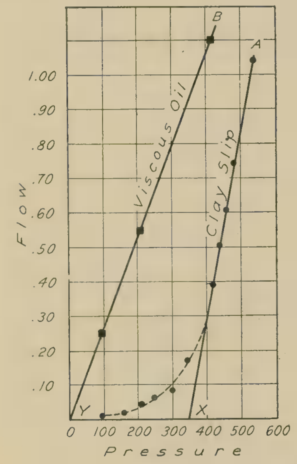
[1] This has been strikingly confirmed by a paper by Bole which appeared after this paper had been written. See *Jour. Amer. Ceram. Soc.*, **5**, 469 (1922).

[2] U. S. Bur. Standards, *Sci. Paper* **278.**



Comparative Flow - Pressure Curves for a Clay Suspension and a very Viscous Oil Through the same Capillary

FIG. 1.

The reason for the difficulties and apparent contradictions encountered in measuring the "viscosity" of clay slips becomes apparent from the above. The calculation of viscosity from a single flow-pressure observation tacitly assumes that flow is directly proportional to pressure. Consider, for example, the two curves on Fig. 1: a measurement at very high pressure would indicate that the clay slip had a lower viscosity than the oil, while measurements at pressures of 100 or 200 gms./sq. cm. would indicate that the clay was more than ten times as viscous as the oil. By determining the complete curves and separating the apparent viscosity into its two components, mobility and yield point, the whole matter becomes clear. An attempt along somewhat similar lines has been made by Bleininger and Ross,[1] who measured the flow through an orifice of various clay mixes under variable pressure, but they drew no conclusions as to the significance of the results, or possible ways of measuring or expressing the two separate factors involved.

Apparatus and Manipulation

The apparatus used was a modified Bingham plastometer, shown diagrammatically in Fig. 2. It consists chiefly of a pressure stabilizer for maintaining constant pressure of several different magnitudes, a container for holding the material to be tested, into the lower end of which is fastened a capillary, and a manometer for measuring the pressure. A general description of the apparatus is given by Bingham in *Proceedings of the American Society for Testing Materials*, Vol. **XIX,** Part II, 1919. The flow meter as described by Bingham and Green was not used in these measurements, but the weight of the discharge and the density of the clay slip was used to determine the volume. The instrument is limited to materials which have a very slow "settling time." For very stiff pastes the pressure range must be great enough to permit the linear portion of the curve to be determined.

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[1] Bleininger and Ross, *Trans. Amer. Ceram. Soc.*, **16,** 392 (1914).

A number of preliminary trials were made to determine what size of capillary seemed most suitable for use on slips in the casting range. The smaller capillaries, such as used by Prof. Bingham, were not found satisfactory in working with clay slips, especially when coarser particles were admixed. When the most suitable capillary was finally selected its dimensions were carefully determined, the diameter by filling it level with mercury and weighing. It was found to have the following dimensions.

Length = 5.020 cm.
Diameter = 1.3624 mm.

The capillary was later measured with a high power micrometer microscope at the Bureau of Standards, which gave a figure of 5.021 cm. for the length and 1.3636 mm. for the average diameter.[1] This capillary was used in all the tests discussed in the paper except where otherwise noted.

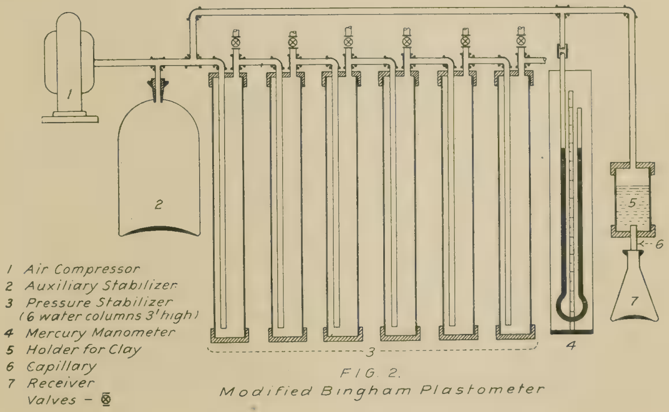

FIG. 2.
Modified Bingham Plastometer

Source and Treatment of Clay Samples

The clays used in these experiments were selected to be representative of the clays that are used in the ceramic industry today.[2] The Georgia kaolin is a white-burning clay, free from grit, and with a soapy feel, due to the presence of many muscovite scales of microscopic size. The North Carolina clay is a kaolin of residual origin that is used extensively for the manufacture of whiteware. The Tennessee ball clay is a very plastic clay of sedimentary character and possesses very good bonding power.

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[1] Calculated from major and minor axes of tube, cf. *Zeitschr. f. physik. chem.*, **80,** 683 (1912).

[2] These were obtained from B. F. Drakenfeld Co., of New York City as representative samples of commercial clays.

The English ball clay is quite similar, in general, to the Tennessee ball clay. The English china clay is a very lean, white-burning kaolin. Several fire clays were tested, but their history was not known. All the clays used, except the ball clays, were subjected to a washing process before they were used. This is the same treatment that they receive before they are put on the market.

The clays were prepared for use by grinding until the entire mass passed the 65-mesh sieve. No attempt was made to separate the clay into different fractions. It is known that very fine grinding affects the plasticity, so it was thought best to use a large capillary in the plastometer and avoid grinding the clay so fine that its character would be changed.

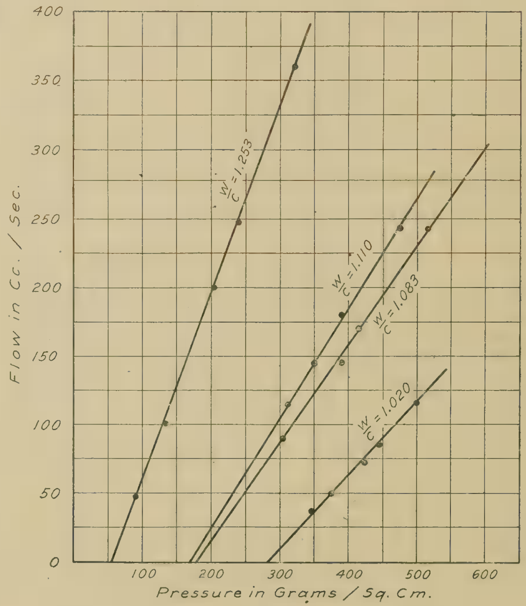

FIG. 3.
Effect of Water Content
on
Flow of Tennessee Ball Clay Slip

All the slips were made by adding weighed amounts of distilled water to a sample of the ground clay as received, but the ratio of water to clay was calculated to a bone dry basis by making determinations of total water content up to 900°C on separate small samples of each clay. The losses on ignition thus determined were as follows:

Clay	Per cent loss on ignition
English china clay..........	14.20
Georgia kaolin.............	11.80
Tennessee ball clay.........	10.25
English ball clay...........	13.00
North Carolina clay........	12.00

Selection of Proper Method of Comparing Plasticities

Fig. 3 shows the results obtained with a Tennessee ball clay slip in which the proportion of water was varied. It is evident that as the amount of water is increased there is a continual tendency to increase the mobility and decrease the yield point of the suspension, and that any yield point or any mobility can be obtained with this or any other sample of clay. The property which is a fundamental characteristic of the clay itself, and which cannot be affected by changing the water content, is the functional relationship between these two.

While the term plasticity is often loosely used to include a variety of properties, such as lack of excessive shrinkage or cracking on drying, a "soapy" feeling in the slip, as well as a peculiar combination of working properties, there is no question but that the most important physical property desired in specifying the use of a "plastic" clay is that it shall maintain a reasonably high yield point after enough water has been added to bring its mobility to a value suitable for working. A clay which is much less plastic can be made to have the same yield point by using a very small amount of water, but it would then be too stiff to work; while if its water content were increased to secure the necessary mobility, the yield point would also drop off, resulting in inability to hold its shape after forming.

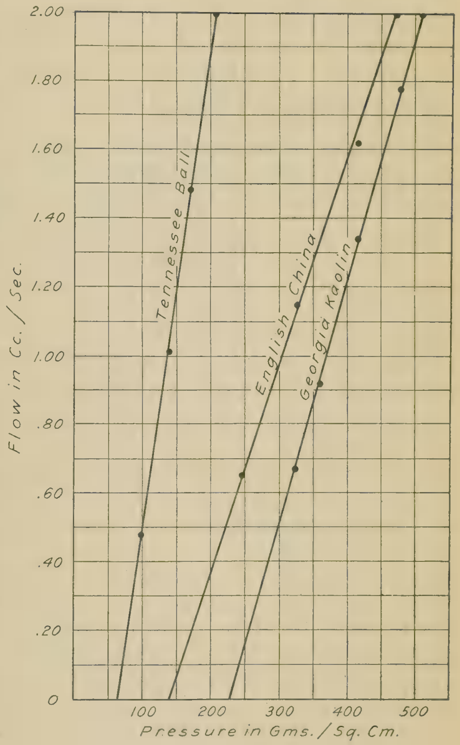

FIG. 4.
Flow of Various Clays with Constant Water Content
$\frac{W}{C} = 1.253$

This brings to the fore the question of the proper basis for measuring and comparing the plasticity of two different clays. One suggestion which has been made is the addition of a definite amount of water to the clay followed by a determination of the flow curve. Fig. 4 shows the results obtained on three different clays with a constant ratio of water to clay of 1.253.[1] It is impossible, however, from an inspection of such results, to decide which is the most plastic clay, because the question immediately arises—if less water had been added to the Tennessee ball clay, thus moving the line to the right, how would its slope compare with that of the other two?

It is therefore apparent that constant water content tests, though quite frequently employed in comparing clays, do not afford a suitable basis for comparison. Instead, the amount[2] of water required to give suitable working properties to the clay is in itself an important property of the clay, which should certainly be determined, but which is distinct from plasticity. It is probably related to the amount of shrinkage on drying.

The question next arises as to how to determine when enough water has been added to give the resulting slip suitable working properties for a given purpose. Several clays of quite different plasticities were made up to possess as nearly as possible similar working properties, and from this test (which should be further confirmed by investigators more closely familiar with ceramic practice) it appeared that clays of *constant mobility* possessed substantially identical working properties. The correct mobility value naturally varies with the purpose for which the clay slip is

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[1] All the figures in the paper are plotted in terms of the actual flow (cc. per sec.) and pressure (grams per sq. cm.) used with the specified capillary. It would be desirable to express these in terms independent of the particular capillary employed, but in view of the previously mentioned uncertainty as to the precise validity of Bingham's simple equations, this has not been done. However, for purposes of comparing results between capillaries which do not vary widely in dimensions, use can well be made of the formula (see Bingham, "Fluidity and Plasticity," p. 323, McGraw-Hill, 1922):

$$\mu = \frac{1.273\, v}{R^3(F-f)}$$

where μ = the mobility
f = the friction or yield value
v = volume of flow in cc./sec.
F = shearing force applied at the wall of the capillary in dynes/sq. cm.
$= \dfrac{980.6\, RP}{2L}$, where
R = the radius of the capillary in cm.
P = the applied pressure in grams/sq. cm.
L = the length of the capillary in cm.

The *calculated* yield values for the capillary used in the foregoing work in terms of *shearing force* in *dynes per sq. cm.* may therefore be obtained by multiplying the graphically determined yield values given in this paper by

$$\frac{980.6 \times .06815}{2 \times 5.021} = 6.65$$

and the mobilities by substituting in the above equation.

[2] In the molding range this quantity is sometimes designated by the ceramists as the water of plasticity.

used, that selected for these tests being considered approximately correct for casting purposes before "freeing out" with alkali.

Clays should therefore be compared on the basis of (*a*) the amount of water required to give a specified mobility, and (*b*) the magnitude of the yield value when this amount of water has been added, this value presumably being higher the more "plastic" the clay. Testing clays by this method unfortunately necessitates working by trial and error and determining two points on the flow curve for each change in the amount of water added, but once the worker is fairly familiar he can approximate the proper mobility quite closely by estimation.

It is, of course, conceivable that by studying a large number of clays to which different amounts of water had been added, a definite functional relationship between mobility and yield value would be found to hold for a given type of clay, regardless of the water content, in which case only one measurement would have to be made. For example, it has been found as a rough approximation that for two samples of clay over a two-fold range of mobilities the yield value × $\text{mobility}^{1.7}$ = a constant, but tests on a third kind of clay did not appear to bear this out. While the foregoing method of defining and measuring the more important physical properties included under the vague term "plasticity" has thus far been applied only to the casting range, there appears to be no fundamental reason why it should not be extended to the molding range, although the high pressures required and the maintenance of steady flow, may present rather serious experimental difficulties.

It should be noted that this way of analyzing "plasticity" into its more important components crystallizes the whole problem and avoids such inconsistencies as the statement of some ceramists that clay passes through a narrow region of "maximum plasticity" in the molding range as the water content is increased. It is certainly highly improbable that any physical property really passes through a maximum with increasing water content, and the popular conception is again believed to be due to the attempt to combine too many properties in a single term. In other words, the region of "maximum plasticity" is in reality simply the region of the most desirable working properties (for molding) between the point where the clay is too stiff on account of insufficient water and too sticky or fluid from too much water.[1]

On account of the loose use of the term "plasticity" which can probably never be eradicated, the writers are inclined to recommend that instead of considering the yield value at constant mobility as a direct measure of "plasticity," that the term be dropped entirely when referring to the physical properties of the slips. If water content and yield value at constant mobility should not be found to comprise all the important properties now included under "plasticity," an additional quantitative measurement and term could be added, but the separate properties of the clay should be accurately measured and uniquely defined rather than using a vague general term which means essentially "good working properties" for certain purposes. The situation is analogous to the change from saying that an oil possesses "good lubricating characteristics" to specifying precisely its flash point, cold test, viscosity at different temperatures, etc.

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[1] A very recent paper on the "Plasticity of Clays" by J. W. Mellor (*Communication from the Clay and Pottery Laboratory*, Stoke-on-Trent, No. 53) has thrown interesting light on this question from a somewhat different point of view.

Comparison of Yield Values and Water Contents at Constant Mobility

For the reasons previously discussed, the water content of six samples of clay was adjusted to give the desired constant mobility suitable for casting and the yield values and water contents at these mobilities compared. The results are shown graphically in Fig. 5.

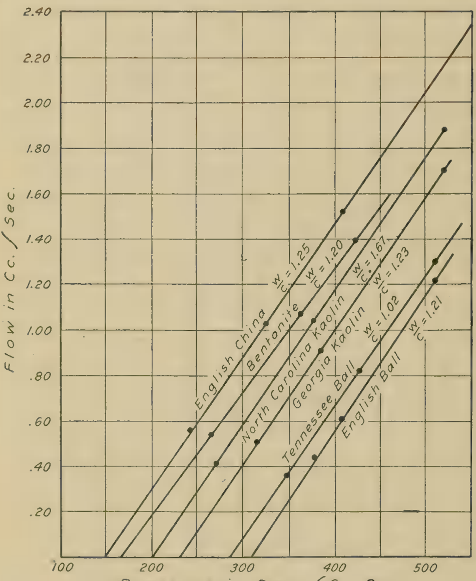

FIG. 5.
Comparison of Yield Value and Water Content at Constant Mobility

Neglecting for the moment the sample of bentonite, it will be noted that the order in which the clays arrange themselves with increasing yield value is as follows: English china clay, North Carolina kaolin, Georgia kaolin, Tennessee ball clay and English ball clay. This appears to correspond very well with the customary belief as to the relative plasticity of these clays and thereby confirms the essential validity of the test. It will be noted that the ratio of water to clay required to give these mobilities is quite variable, being as low as 1.02 for the Tennessee ball clay and as high as 1.67 for the North Carolina kaolin. Of the samples tested, the kaolins on the average required more water than the ball clays. The futility of comparing different clays at constant water content is obvious.

One very interesting sample is the bentonite, a very peculiar soapy clay of which there are large deposits in Wyoming.[1] Although the bentonite is customarily spoken of as being extremely plastic, it will be noted that on the selected basis of comparison its yield point is rather low, but that the ratio of water to clay required to give the desired mobility is many times as high as for any of the standard clays. It is probable that the common statements with regard to its plasticity are again based on a confusion of ideas resulting from the tendency to make plasticity cover too wide a range of properties. It is, of course, possible that when added in small amounts the remarkable properties of the bentonite might make a lean slip much more plastic, by coating the larger particles, or filling in the voids so as to give a closer packing effect such as that sought in concrete.

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[1] Tests on the bentonite were made later by Mr. C. E. Ronneberg of this Laboratory with a capillary which differed slightly in dimensions, but the results were corrected to make them comparable.

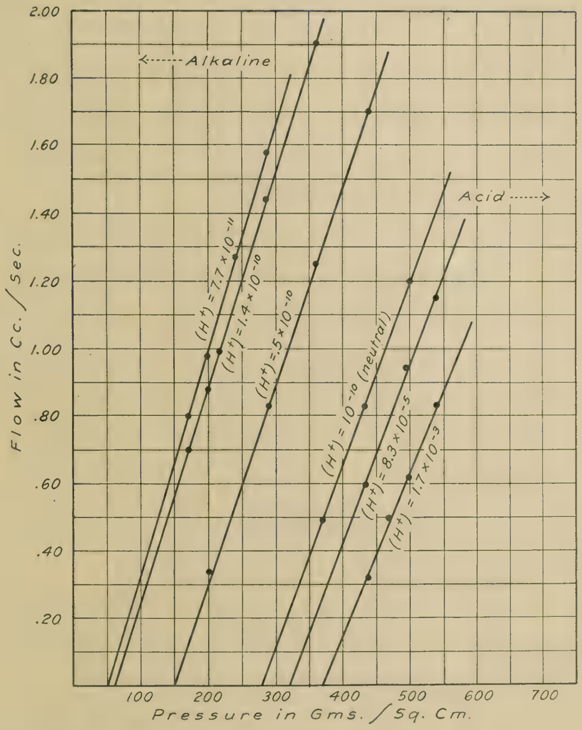

FIG. 6.

Effect of Varying Alkalinity and Acidity of Tennessee Ball Clay

$\frac{W}{C}$ constant at 1.082

Effect on Yield Value and Mobility of Variations in Acidity and Alkalinity

Having pointed out the two essential physical properties involved in plasticity, it is interesting to study the various methods which are used to modify the working properties of clays and determine just how they influence the fundamental variables of yield value and mobility.

For example, it has long been recognized that the acidity or the alkalinity of the water makes a marked difference in the working properties of the clays. Experiments were therefore carried out with Tennessee ball clay slips of constant water content but widely varying hydroxyl or hydrogen-ion concentration, obtained by adding NaOH or HCl to the water. The hydrogen-ion contents are calculated from the amounts added to the water, rather than being measured in the clay slips themselves.

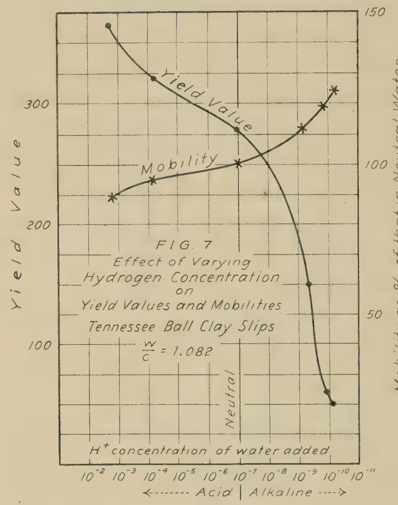

FIG. 7
Effect of Varying Hydrogen Concentration on Yield Values and Mobilities
Tennessee Ball Clay Slips
$\frac{w}{c} = 1.082$

The results shown in Fig. 6 bring out the surprising fact that very wide variations in the hydrogen-ion concentration have only a negligible effect on the mobility, but gradually varied the yield value from 50 in alkaline solutions up to 370 in acid solutions. The function of alkalies in "freeing out" the clay, and of acids in "setting up" the clay, thus becomes quite apparent. It is also worthy of note that the yield value of at least this sample of clay can be varied by moderate additions of acids or alkali to cover a wider range than the whole series of commercial clays when mixed with distilled water. The necessity, and indeed the potential value, of controlling the hydrogen-ion concentration of clay slips therefore becomes obvious.

Fig. 7 shows graphically how the observed yield value and mobility varies with the H^+ concentration—the sharpest change in the yield value is obviously between a calculated *pH* of 8 and 10.

Effects of Additions of Non-plastic Materials

Fig. 8 shows the effect of adding varying amounts of finely ground sand ("Potters flint") to the clay slip, keeping constant, however, the ratio of water to total dry solids. The flint obviously does not hold nearly as much water as the clay and the effect of replacing clay with flint is therefore similar to that of adding water to the slip, increasing the mobility and decreasing the yield. It rather appears, however, that the effect on yield is less than that on the mobility in comparing the results with the addition of water alone. Additional tests should be made on mixtures of constant mobility and of constant ratio of water to clay, but variable amounts of flint.

The foregoing study is obviously preliminary in nature, but it is being continued by the junior author at the Bureau of Standards, a thoroughgoing investigation of the whole problem being under way.

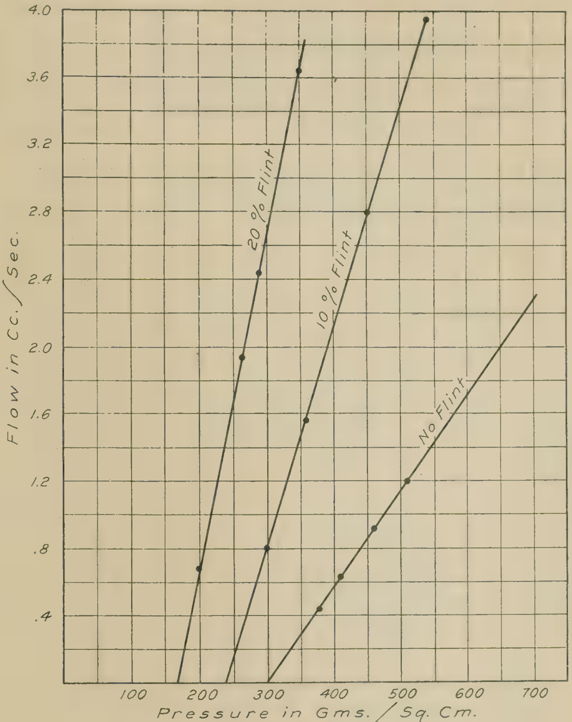

FIG. 8.

Effect of Finely Ground Flint on Flow of E.B. Clay Slip

$\frac{W}{C+F}$ constant at 1.21

The writers desire to acknowledge the helpful suggestions of Dr. Bingham in connection with the inauguration of the work and the preparation of the paper.

Research Laboratory of Applied Chemistry
Massachusetts Institute of Technology
Cambridge, Mass.

THE MECHANICAL MOVEMENT OF WATER THROUGH CERTAIN CLAYS AND ITS CONTROL[1,2]

By H. G. Schurecht

ABSTRACT

Introduction.—Ceramic bodies containing Georgia clay cast and release from the molds slower and have a greater tendency to crack in drying and burning than similar bodies containing English china clay. Experiments were conducted to improve these properties of Georgia clays by studying the movement of water through them and its control.

Permeability.—It was found that the permeability of the clays to water was independent of the time between 2 and 10 days; that is, P is nearly constant in the formula $P = \frac{W}{T}$, in which W is the total water which has passed through and T is the time in days. This factor for North Carolina kaolin was $1.55 \pm .05$; for English china clay $1.45 \pm .06$; for Georgia clay $0.938 \pm .07$; for South Carolina clay $0.673 \pm .07$; and for Tennessee ball clay $0.64 \pm .08$.

Capillarity.—The investigation showed that the capillary rise of water through these clays may be expressed by the formula $H = C_h (\log T - 1.041)$ in which H is the height attained by the water in time T, and C_h is approximately constant for each clay between 10 and 250 minutes, that is, it represents the movement of water through clay when it contains a certain amount of water below that required for saturation. This factor for North Carolina kaolin is 6.67 ± 0.30; for English china clay 7.30 ± 0.70; and for Georgia clay 4.66 ± 0.80. The great capillary conductivity of water through primary kaolins explains why bodies containing these get drier and release from the molds quicker than those containing secondary clays.

Methods for Improving Georgia Clay.—The permeability factor of Tennessee ball clay was increased from 0.64 to 1.20 by adding 0.7% NaOH, and that of kaolin from Dry Branch, Georgia increased from 0.938 to 1.72 by calcining to 450°C. By either, or a combination of the above treatments, it was possible to improve the properties of many Georgia clays, making them more like the English china clay in regard to permeability to water.

Introduction

Although the Georgia white clays have been successfully substituted for foreign kaolins in dust pressed ceramic bodies, the American potters still prefer the primary kaolins like the English china clay to the Georgia white clays for casting and jiggering. Our supply of high-grade primary kaolins is limited and not sufficient to supply the demand and, therefore, a very large part of such clays used in this country is imported from England.

The secondary white clays like those from Georgia, however, are very abundant, and if these can be substituted satisfactorily for English china clay, this country would be independent of foreign importations.

In utilizing Georgia clays in casting slips, it has been found that the slips cast and release from the molds much slower than those containing English china clay. This is due largely to the fact that the Georgia clays are finer

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[1] By permission of the Director, U. S. Bureau of Mines.

[2] St. Louis Meeting, February 27, 1922.

in grain[1] than the English clays and, therefore, more resistant to the conductivity of water through them.

Still another objection to Georgia clay is that it cracks on drying and burning when moulded by the plastic process.

With the object of improving the working properties of Georgia clays, the writer made a study of the permeability and capillary movement of water through clays in both the plastic and dry states.

Experimental Methods

The permeability of clays to water was measured by means of the specially designed apparatus shown in Fig. 1. The clay or body to be tested in the plastic condition is mixed with water to normal consistency[2] and pressed into a cylindrical hole having 1 cm. diameter in the lower rubber stopper. Filter paper is sealed to the stopper above and below the clay by means of paraffin, to prevent the clay from mixing with the water. The cylinder is then filled to the 12.75 cm. mark with distilled water and the upper stopper with glass tube placed in position as shown.

The cylinders are weighed at the beginning of the test and at intervals up to 30 days, during which time they are kept in a constant temperature chamber. By determining the loss in weight at intervals, the amount of water passing through the clay may be calculated. Each time the cylinder is weighed it is refilled with water to the 12.75 cm. mark, thus keeping the water pressure approximately constant.

The capillary movement of water through clays was measured with the apparatus shown in Fig. 2. The raw unburned clay test piece is placed in the glass container where it rests on a piece of filter paper over a copper screen fastened across the bottom of the cylinder. The cylinder is then lowered into the cup, in which the water level is kept constant, until the bottom of the test piece touches the water. The glass cylinder containing the clay test piece is weighed before the test and at frequent intervals as a measure of the rate of absorption caused by the capillary rise of water.

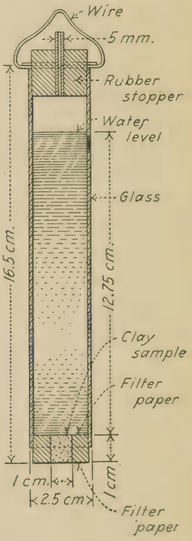

FIG. 1.—Apparatus for measuring the permeability of clays to water.

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[1] H. G. Schurecht, "The Microscopic Examination of the Mineral Constituents of Some American Kaolins," *Jour. Amer. Ceram. Soc.*, **5**, 3 (1922).

[2] By normal consistency is meant that consistency at which the clay contains a maximum amount of water without being sticky.

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The height of the water is also measured at intervals. This is continued until the cylinder comes to constant weight. By adding a small amount of aniline dye to the water the height of the absorbed water may more plainly be seen.

To study the effect of additions of varying amounts of NaOH on the permeability of clays, 0.1, 0.2, 0.3, 0.5, 0.7, 0.9, 1.2, 1.5, and 2.0% of NaOH were added to plastic clay samples and permeability tests were made according to the above method.

The effect of low calcination temperatures on the permeability of Georgia clays was studied by calcining the clays to 200°, 300°, 375°, 400°, 425°, 450°, 475°, 500°, 550°, and 600°C and holding them at these temperatures for one hour. Permeability tests as outlined above were then made on these samples.

Each clay sample contained a definite amount of water at the end of the test, which was also determined and expressed in terms of the dry weight of clay.

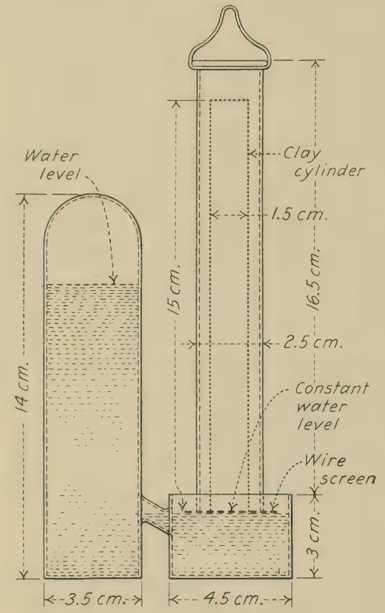

FIG. 2.—Apparatus for measuring the capillary rise of water through clays.

Experimental Results

Permeability of Clays to Water.—In Fig. 3 are shown the results of tests on the permeability of clays to water. It is obvious that North Carolina kaolins and English china clays are much more permeable to water than Georgia clays, South Carolina clays, and Tennessee ball clays. This,

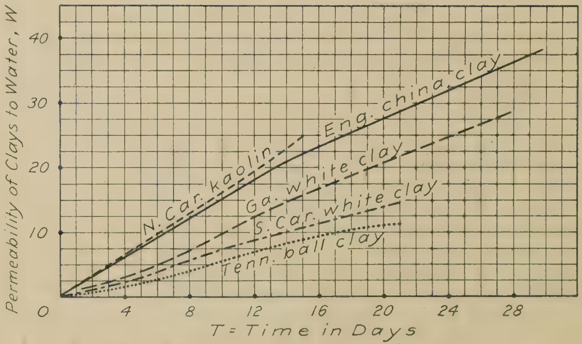

FIG. 3.—The permeability of clays to water.

therefore, explains why the primary clays like the English china clay and North Carolina kaolins produce faster casting bodies than the secondary clays like Georgia clay, South Carolina clay and Tennessee ball clay.

Between 2 and 10 days the permeability of clays to water may be approximately expressed by the following formula, which was derived from the data obtained in this work:

$$P = \frac{W}{T}$$

P = grams of water passing through 1 cm.^{3} of plastic clay in 1 day.
W = total grams of water passing through 1 cm.^{3} of plastic clay in time T.
T = time in days.

P is found to be approximately constant for each clay and was used to compare the permeability of different clays to water.

The permeability factors for the different clays are shown in Table I.

TABLE I

THE MECHANICAL MOVEMENT OF WATER THROUGH CLAYS

	Permeability of clays to water		Capillary movement of water through clays		
Clay	P—Grs. of H_2O passing through 1 cm.^{3} of plastic clay per day	Per cent water in clay at end of test	C_h capillary factor	C_w adsorption factor	Remarks
North Carolina kaolin	1.55± 0.05	54.2	6.67± 0.60	2.28± 0.30	Clay softened and deformed somewhat during the test.
English china clay	1.45± .06	49.1	7.30± .70	2.81± .35	Clay softened only slightly during the test.
Georgia clay	0.938± .07	41.9	4.66± .80	1.83± .40	Clay softened and deformed badly during the test.
South Carolina clay	0.673± .07	32.3	...	...	...
Tenn. No. 7 ball clay	0.640± .08	42.2	...	...	...

The per cent water in the clays at the end of the test is also shown in this table. It is obvious that the coarser grained clays contain a higher water content than the finer grained clays. This may be due largely to the fact that the per cent void space in the coarser grained clays is greater than in the finer grained clays.

Capillary Movement of Water through Clays.—In Fig. 4 and Table I are shown the results of the capillary movement of water through clays. This movement is faster through English china clay than through North

Carolina kaolin for the first 250 minutes. This may be due to the fact that North Carolina kaolin contains more of the extremely fine particles[1] than the English china clay which would fill the voids and retard the flow. The rate of capillary rise of water through the English china clay and North Carolina kaolin is greater than that through Georgia clay for the first 250 minutes and after this the rate becomes greater for the Georgia clay than for the primary clays.

Buckingham[2] in discussing the theory of capillary conductivity of water through soils states that the conductivity varies with decreasing water contents as follows: (1) the soils have the largest conductivity with a saturated water content and as the percentage of water decreases, the number of capillary paths become less and the conductivity decreases; (2) when most of the capillary paths have been broken, the film paths become important and there is a rather rapid decrease in capillary conductivity; (3) as the water content decreases the film paths change from short to long paths with a comparatively small decrease in conductivity; (4) as the soil approaches dryness, the films begin to break or lose the property of liquid water and there is a rapid decrease in capillary conductivity to zero.

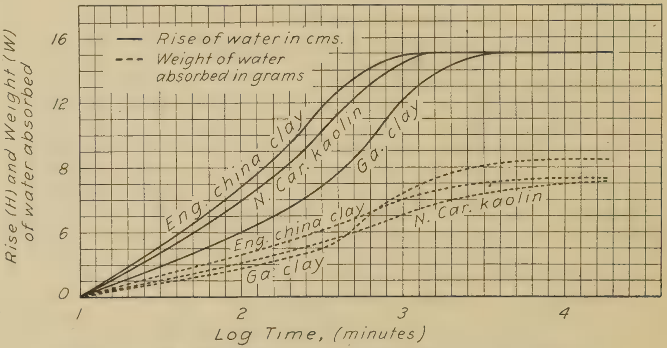

FIG. 4.—Capillary rise and weight of water absorbed.

Similar to what Buckingham claims for decreasing water contents, the writer found corresponding changes in the conductivity with increasing water contents. A rapid increase in conductivity in each clay was noticed for the first 10 minutes as the water content increased, which may be due to the rapid formation of a large number of water film paths. Then between 10 and 250 minutes the rate of rise of water is slower which would correspond to that period in which the long film paths change to short paths. Between 250 and 2000 minutes there is an increase in conductivity which according to Buckingham would represent that period in which the film paths change to capillary paths and after this period the rise is only slow until the clay becomes saturated. Between 10 and 250 minutes the rise of water may be approximately expressed by the following equations which were derived from the data obtained in this investigation:

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[1] H. G. Schurecht, "Sedimentation as a Means of Classifying Extremely Fine Clay Particles," *Jour. Amer. Ceram. Soc.*, **4**, 812–821 (1921).

[2] Edgar Buckingham, "Studies on the Movement of Soil Moisture," Bureau of Soils, *Bull.* **38** (1907).

$$C_h = \frac{H}{\log T - 1.041} \text{ or } H = C_h (\log T - 1.041),$$

C_h = capillary factor which is nearly constant for each clay.
H = height of water in cms. at different intervals of time.
T = time in minutes.

$$C_w = \frac{W}{\log T - 1.041} \text{ or } W = C_w (\log T - 1.041).$$

W = grams of water absorbed per cm.^{2} for different intervals of time.

Gardner and Widstoe[1] and Washburn[2] studied the capillary movement of water through soils and porous bodies and Washburn derived an expression in which the distance penetrated by a liquid flowing under capillary pressure in a horizontal capillary or one with a small internal surface is equal to the square root of $(\gamma\ rt \cos.\ \Theta/2n)$ in which γ is the surface tension, Θ the angle of contact, t the time, n the viscosity and r the radius of pores. Although an exact comparison between this expression and that derived from the data in this investigation are not possible because of insufficient data, the general shape of the curves derived are similar.

Although the movement of water through clays containing less than a saturated content is not essential to the speed of casting of a clay slip in a plaster mold, it becomes important after the slip has been poured from the mold and the water content in the casted shell decreases. During this stage the casted ware sticks to the mold until its water content becomes sufficiently low to prevent this stickiness. Those bodies containing clay from which the water moves rapidly reaches this stage before those containing clays from which the water is conducted slowly. Therefore, bodies of the former type will release and may be taken from the molds quicker than those of the latter type.

It was found in this work that the capillary movement of water through the primary clays is faster than that through secondary clays at certain stages when this content is decreased below saturation, and this may explain why bodies containing primary clays release and may be taken from the molds quicker than those containing secondary clays.

Between approximately 250 and 2000 minutes there is an increase in conductivity with an increase in time which may be due to the change from film to capillary paths as is explained above which is especially noticeable with Georgia clay. The capillary movement of water through Georgia clay is slower than that through English china clay and North Carolina kaolin for the first six hours, but after that it is faster than that through the primary kaolins and the final amount of water absorbed is also larger. The fact that water rises to a greater height in Georgia clay than it does in primary kaolins may be explained by examining the following equation:

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[1] W. Gardner and J. A. Widstoe, "The Movement of Soil Moisture," *Soil Science*, **11**, 215–232 (1911).

[2] E. W. Washburn, "The Dynamics of Capillary Flow," *Phys. Review*, **17**, 273–283 (1921).

$$H = \frac{2\,Y}{grd}$$

H = capillary height in cms.
g = 981, the gravitational acceleration in cms. ÷ sec.^{2}
r = radius of the capillary tube.
d = density of the liquid at the temperature of observation.
Y = surface tension in dryness per cm.

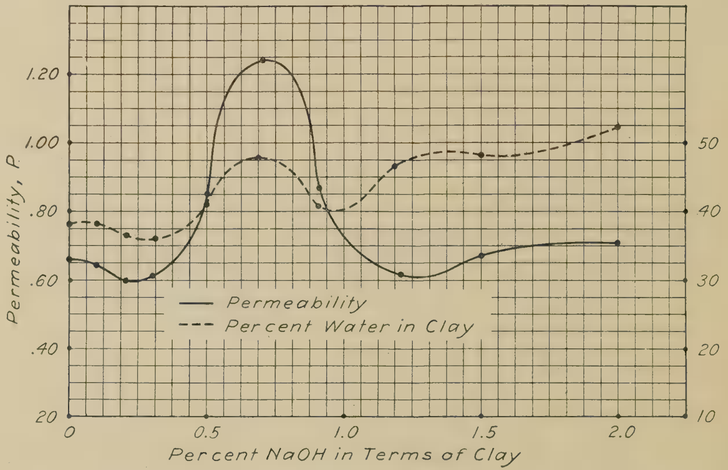

FIG. 5.—The effect of NaOH additions on the permeability of Tennessee ball clay to water.

In examining this formula it is obvious that the total height H is greater when the radius r is small. Since Georgia clays are much finer grained than the primary clays, the voids are smaller and hence r is much smaller, which causes the total height of absorbed water to be greater with Georgia clay than with the primary clays. A value varying with the average size of the pores may be calculated by noting the total height of water in the specimen. The resultant force causing the capillary flow of water through clays is evidently greater in the Georgia clays than in the primary clays because the value r is smaller in this case, but the higher resistance of Georgia clay to this flow causes the actual movement to be slower. After six hours the force of gravity on the water in the primary clays is so great that the rise of water in the secondary clays becomes faster than that through the primary clays.

The bars prepared from Georgia and North Carolina clays deformed more than those of English china clay, due to softening. This is evidently caused by the larger percentage of extremely fine clay substance in the Georgia clays which restricted the flow of water, thereby causing the lower portion of the bar to become saturated with an excess of water and hence causing it to soften and deform.

The Effect of Addition of NaOH on the Permeability of Clays to Water.—The results of NaOH additions on the mechanical movement of water through clays is shown in Fig. 5. These results show that the permeability decreases when 0.2% of electrolyte is employed. Upon adding more NaOH there is a remarkable increase in permeability, this being much greater than the initial decrease. This increase is probably due to the fact that the clay is in a flocculated or partially flocculated condition, which causes the aggregates of fine particles to act as coarser grains and hence cause the mass to have larger voids between the aggregates.

It is therefore possible by adding the proper amount of electrolytes to secondary clays to make them as permeable to water as English china clay. Adding a percentage below that required for maximum flocculation, *i. e.*, less than 0.7%, would evidently give better results than are obtained by adding an amount causing maximum or minimum deflocculation, since bodies containing sufficient NaOH to cause maximum deflocculation cast in very thin layers while bodies containing sufficient NaOH to cause maximum flocculation do not drain clean and tend to stick to the mold.

The Effect of Low Calcination Temperatures on the Permeability of Clays to Water.—The results of low calcination temperatures on the permeability of clays to water are shown in Fig. 6. It is obvious that there is but little change in the effects produced by calcining at low temperatures until the clay is heated above 400°C. Here there is a sudden increase in permeability reaching a maximum at 450°C, and then it remains practically constant up to 600°C. This change occurs when the clay decreases in specific gravity[1] and is evidently closely related to the increase in volume of the clay which occurs at this temperature.

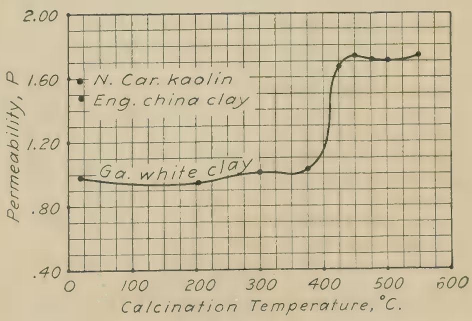

FIG. 6.—The effects of low calcination temperatures on the permeability of clay to water.

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[1] J. M. Knote, "Some Chemical and Physical Changes Due to the Influence of Heat," *Trans. Amer. Ceram. Soc.*, **12**, 227–264 (1910).

The permeability of water through Georgia kaolin can be made greater by calcination than that through English china clay or North Carolina kaolin. Although the clay has lost some of its plasticity by being calcined at this temperature, it is still plastic, comparing favorably with the plasticity of English china clay. The tendency of Georgia kaolin to crack during drying is reduced. This was anticipated, since Bleininger[1] used the preheating method for improving the drying properties of joint clays which cracked badly in drying.

In comparing the permeability of Georgia clay calcined at 450°C with that of English china clay and North Carolina kaolin (see Fig. 7) it is found that it is greater than that for these clays. The permeability of the calcined clay does not revert back to that of the raw clay upon standing in contact with water for 28 days as is shown by the permeability curve. We would expect, therefore, but a slight change in the permeability of calcined Georgia clay upon aging for a period of 28 days.

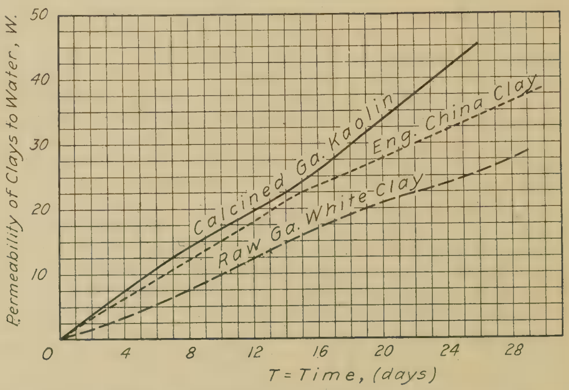

FIG. 7.—The permeability of calcined clay to water.

It may therefore be possible to treat Georgia clay by calcining at 450°C, and thereby overcome to a degree at least, its objectionable casting behavior. In conclusion the writer wishes to state that the above results are merely laboratory results and whether the above methods can be used successfully in practice will have to be determined by subsequent tests.

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[1] A. V. Bleininger, "The Effect of Preliminary Heat Treatment upon Clay," *Trans. Amer. Ceram. Soc.*, **11**, 392–406 (1909).

USE OF OX GALL IN PREVENTION OF CRAWLING OF GLAZES

By H. Spurrier

ABSTRACT

The crawling of glazes may be entirely prevented by the use of ox gall in solution. The action is probably due to the lessened surface tension.

Some time ago, it was desired to glaze over an underglaze decoration in which the medium was oily so that a single fire might suffice instead of the usual two-fire method.

At first the prospect of success did not look very rosy and any effort in this direction seemed foredoomed to failure. It occurs, however, that artists sometimes use a preparation of ox gall to cause water colors to "take" on paper that has become greasy. Accordingly an ox gall preparation used for art purposes was secured and it was determined to try it out. The material was a light yellow limpid liquid, quite clear and without any fluorescence. A small quantity of this liquid was added to the glaze and the pieces were dipped, the glaze so treated covered well and gave promise of good results. The pieces were fired as usual and came out very well.

This circumstance led to an effort to find other materials that would do the work and not be so expensive as the artists' material.

Many and diverse materials were tried out and only one other was found that in any way served the purpose, and this none too well. The material was sulphonated castor oil also known as Turkey red oil or soluble oil. No further work was done in this connection for some three years, until recently. A bad case of "stripping" brought the former work to mind.

Owing to the presence of oil in dust-pressed ware, a certain colored glaze could not be made to cover, and the most aggravated stripping occurred in the kiln, rendering the pieces entirely unsuitable. In the meantime, a new source of ox gall was secured. This time the gall was in the paste form but very much cheaper, and is known as inspissated ox gall and was supplied by a large drug house in Detroit. On using this material such startlingly good results were obtained that some investigation was made in order to ascertain the underlying cause for the results.

It was noted that an aqueous solution of the material seemed to show a much lessened surface tension, and while this would undoubtedly help the aqueous glaze to cover the greasy or oily surface it was somewhat difficult to see how this should affect the firing behavior so strikingly. In order to test out the influence of the lessened surface tension, a cake of paraffin wax was dipped into a glaze containing a small quantity of the ox gall. On withdrawing the cake a thin even layer of glaze had become attached to the wax which was laid down flat to see if the film would "break." This however did not take place, and the glaze dried up completely having covered the wax to the extreme edges and somewhat over the sides and ends. Moreover the dried residue was quite adherent, and when the thicker portions (which accumulate on withdrawing) were punctured with a pointed blade the glaze did not fly off as would be the case on ware.

A careful comparison of pieces of ware both with and without oil, glazed with the usual glaze, and with that containing ox gall, shows that the gall has the effect of producing a much more intimate bond between the glaze and the unfired body.

In no case, no matter how thick was the glaze on the body, could any hair cracks be seen with a × 10 Coddington lens.

In order to secure more information on the subject a letter addressed to Mr. H. C. Hamilton, research chemist with Parke, Davis & Co., who manufactured the ox gall, brought the information that they proceeded as directed in the U. S. Dispensatory where the following information is given.

"The composition is rather indefinite, and it is a mixture containing fats and coloring matter, along with the glycocholates and taurocholates of sodium and potassium." Mr. Hamilton suggests that "it may be that some obscure or unknown constituent is responsible for the peculiar action noted."

It is astonishing how small a quantity of ox gall will suffice to entirely stop the most aggravated cases of "crawling" as the following case in point will illustrate. A glaze batch of over two hundred pounds of solids of blue glaze was completely cured of severe crawling by the addition of three ounces of ox gall dissolved in part of the added water, in all the ware on which this glaze was used not a trace of crawling was to be found, whereas previously, no perfect specimens could be found. So far the only difference that can be detected, is the already noted close adherence of the glaze to the body and a rather smoother surface of the raw glaze when applied to dust pressed ware. As the addition of even a very small amount of ox gall to a glaze causes it to froth copiously in the mill, it is better to make the addition, after milling and lawning, by dissolving the required amount in a small quantity of water and gently stirring this solution into the glaze till thoroughly mixed.

It is not at all unlikely that further work on this subject will make it possible to develop a pure principle which will do the work of ox gall even more potently.

As ox gall preparations are highly complex, containing beside fatty matters, many bile acids, trypsin, cholesterol, etc., it might be possible to isolate those compounds which produce the desired effect. This seems the more likely as Ernst Joel in *Biochem. Zeitung* notes that glucose and acetone tend to reduce viscosity slightly, while bile serum reduces it to a much greater extent in secretory liquids.

Square D Co.
Peru, Ind.

THE WITCHERY OF GLAZES[1]

By Paul E. Cox

ABSTRACT

A paper showing the extent of research possible in glazes and the fascination of the work in that field. It is implied that the general chemist has little to offer to shorten the road that must be followed and that the work is reward enough for the labor involved. It is shown that the artistic temperament functions in this work along with the scientific temperament.

In the museum of the Louvre, in the section devoted to Egyptian ceramics, there is a scarab about the size of a man's hand. There are many hundreds of scarabs of many sizes all about this specimen but this one is peculiar in that it has been subjected to a reducing fire and the wings have developed the bronze color characteristic of copper-bearing glazes which have been fired in a strongly reducing atmosphere, while the body has touches of green, blue and red. The whole is very interesting to the student of color. No other specimen shows any such treatment and it would be entertaining to know exactly what happened in the mind of that craftsman when he took from his furnace this result which probably is better than the turquoise color which was sought. Doubtless another brain than the potter's decided that this one was of value, for the glaze maker is quite often too close to the job in hand to realize that accident often gives results more pleasing than those sought for, and a taste trained in another school quite often helps the craftsman to the step forward. Had there been several specimens of copper red glazed scarabs the conclusion would be that the Egyptians understood very well that process that later on made the lustred wares of Italy. But the single specimen makes speculation pleasant and a writer of the character of H. Rider Haggard might very well make a best seller story telling what things happened to the man who made a bronze and green scarab when a turquoise blue one was expected.

The chemist is concerned with the process by which the turquoise glaze can be produced and finds that copper in an alkaline glaze gives what is desired and that this glaze subjected to a smoky atmosphere will yield reds and coppery lustres. He furthermore finds that white sand bound with some of the glaze was the medium from which the scarabs were fashioned. If the chemist is an analyst only he may be satisfied to have established the proportions of the various ingredients, and the best process for getting his results. He may indicate his opinion as to how the reduction might be controlled today, but if he is also a ceramist he will marvel at the skill required to make so short a mixture as sand and glaze would have to be into the little figures that are so abundant among the things left from that civilization. And the ceramist will draw the lesson that if these objects could be glazed, together with some other kinds of things the Egyptians did, there are very few things that will stand fire that cannot be glazed if a glaze is wanted for them. And so the ceramist falls under the spell of the glaze witch.

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[1] Read at the meeting of the Exposition of Chemical Industries, New York, September, 1922.

The story of Bernard Palissy is too well-known to need more than mention to bring to the mind of every student of literature the point that it was the baffling character of the work that kept this more than ordinarily talented man digging away to an end that after all was not the thing he wanted to do but which gave him more fame than success in porcelain making possibly would have done. It was the witchery of the business that made him carry on, and the man is not so much known for his product as he is known for his yielding to the charm of glazes and ceramic colors.

Professor Chas. F. Binns used to tell his students that ceramics is more an art than a science and certainly this is true in the field of glaze making. Chemistry as known to the general chemist is of the greatest help to the ceramist, but nothing as yet has developed that makes it possible to do away with an empiric process of glaze development and hence there is always ahead of the experimenter the possibility of a combination of both scientific and artistic interest. It is the unknown that makes the drudgery of the work endurable, and few investigations fail to yield color variations, texture variations or some sort of differentiation from the beaten path that intrigues. The phrase maker might define art as the juggling with the infinite, and the artist as the one who does this. The glaze maker certainly is juggling with the infinite at all times. He must have, to be most successful, that sort of imagination that has developed within the modern school of painters (not the ultra modern). Such an imagination is necessary that will recognize effects applicable to terra cotta and other massive ceramics, as well as effects suitable for dainty pottery of the boudoir or dining room. In other words the glaze-making ceramist is successful in proportion to his culture, exactly as this is true in the field of art and for the same reasons. His imagination must be active and imagination is that thing which is stimulated by any works which may bewitch.

Time and temperature are the "Gold Dust Twins" that have long been recognized as factors in ceramic work, and the physicists and the physical chemists have worked to develop control of these factors in ceramic work. The enameled iron glaze maker will make an enamel that he can fire in half a minute but if he leaves it in the furnace a long time it is ruined. Glazes may be successful in a quick fire on light wares and useless on heavy wares in a long fire. It would be very simple to make glazes if we could say for example that the lime content varies directly as the temperature and inversely as the time, but we cannot because we have many other factors to take into account. If the glaze is used on a clay, the clay is being slowly dissolved and doubtless a glaze is a series of layers each merging into the other, the whole being the subject of spurts of flame and of cooler gases here and there over the surface so that control is difficult to imagine. We hear of kilns that are to have slight variations top and bottom or side to side but we know that after all our glazes must be made up with the greatest flexibility as to variations in treatment if we are to produce results that we can market. It is this difficulty combined with the infinite varieties of glazes possible that form the pot of gold and the end of the ceramist's rainbow and keep him ever interested.

The common stoneware business has become senile for the same reason that John Barleycorn is legally dead. People became tired of the bother that whiskey made and one of the products made in the stoneware shop was jugs. So common and coarse a product as stoneware had the greatest interest in the glazes. Salt glaze is not easily handled, yet by the selection of clays and the manipulation of the kiln some of the best ceramic products are possible, a truth known long before anything like accurate chemical processes had been developed. The Martin art pottery of England is not surpassed so far as merit is concerned by any type of pottery made today and the difficulty of securing exactly the results desired must make the work of the greatest interest to the potters concerned. Technically the wares are common stoneware. No one has carried out the idea of making use of the slip clays for art pottery work though years ago Griffin suggested such a scheme, and showed how the slip clays might be modified to suit the needs of the artist to some degree. It is conceivable that by making use of slip clays only that a stoneware might be produced of the same warmth almost as the early Rookwood with its browns and yellows. A slip clay has recently been submitted to the writer that is said to yield a colorless or slightly yellow clear glaze and if tests show that to be true, this clay mixed with Albany slip clay and with Michigan or Seneca Falls slip clays and with one or two others known to the more mature of the stoneware men a rather interesting color palette would develop. This, if used on stoneware clays in the unfired state, would yield a technically very interesting art pottery. The fascination of such a work would be akin to any other research work in any field. And the difficulties would be abundant enough to stimulate interest quite like that shown by Palissy, though success would come with less starvation along the road than fell to that hero of ceramics.

The glazes of the type known as Bristol glazes have gotten into dignified company by having come into use in terra cotta work, but used in the manufacture of jugs and jars they were interesting to dabble with because slight variations in the proportions of the ingredients made such differences in the results. One manufacturer bought air separated whiting, thus having a material that was so fine it was almost a liquid. Glazes made up from this material did all sorts of things that made trouble and while he was not glad to lose his ware he enjoyed the knowledge he gained from the experience. A white Bristol glaze, made white by zinc oxide in suspension can be cleared and made into a transparent glaze by the addition of flint or by the addition of lime, neither process making any appreciable difference in firing temperature needed to mature the glaze. Zinc oxide kills greens, lightens blues, makes crystals, and does many interesting things so that any glaze maker has on the one hand the temptation of cheapness prompting him to make use of glazes of the Bristol type and on the other hand the color problem to solve weighing against such use. This has developed several papers showing results of research that point out how interesting such research can be.

Karl Langenbeck in his "Chemistry of Pottery" points out that it is impossible to cover the possibilities of any glaze by any single statement of its composition because of the influence of the otherwise colorless ingredients of the glaze on the chromatics. That is, a statement of the composition of a colorless glaze can be given but trial must be had before a statement of what this glaze will look like for every stain added to it. Or a glaze may have a certain color but for some reason a change may be thought desirable in the ingredients that would with no colorant present produce a colorless glaze and a vital change in the color of the glaze would result. It is necessary therefore always to test out such work and to adjust for each change made. Such procedure demands exact work that is interesting indeed. Changes of temperature from top to bottom of the kiln likewise affect the tints and often the glaze has to be adjusted to meet these conditions.

Texture is likewise profoundly influenced by the variations of the ingredients in a glaze and the European potter has been careful to state the source of his raw material as well as the chemical composition of it, because he knows that the physical conditions have influence quite as much perhaps as the chemical conditions. Because of these facts there are times when a recipe is worth keeping secret and it can be kept secret by failure to report the source of raw materials.

Defects have been made into virtues in the potter's craft from time immemorial, and we have but to note how crazing properly taken advantage of has made more than one type of pottery glaze of the greatest interest.

The glaze maker has a wide field for his work. There is true porcelain fired in these days to almost any temperature possible to obtain sagger mixtures refractory enough to permit temperature. The color palette is limited at high temperatures but there is ample incentive for investigation at high temperatures for aesthetic reasons as well as for reasons of science. Any person working with a really capable artist will find that the artist finds pleasure backed with good reasons in the qualities of glaze and color due to high temperatures and those admirable volumes by Burton on porcelains point out constantly what an important part the glaze maker has played in the production of quality porcelains through the ages. The literature of ceramics tells of the beauty of body and glaze of the soft porcelains but we have done little in America with this interesting type of porcelain if we except Beleek made in Trenton. America has not yet made bone china of any great merit or amount and there will be adaptations of English practice to American materials when this kind of ware is developed here. Our domestic whitewares will lend themselves to treatments in colored glazes and though it may be suggested that the use of colored glazes on white bodies is wasteful the ceramist knows that certain kinds of bodies yield refinements in glazes that make the expenditure worth while. Any worker in glazes who has made use of the little floor tiles that are so hard and are feldspathic knows that the quality of glaze is superior to the glaze obtained on coarser bodies.

Our secondary fire clays have been made use of but slightly in the making of fine stonewares. Chas. F. Binns has done more with them than any other worker and he is not engaged in commercial life so that few people know that work of the type he has done brings out the maximum beauty of our very abundant stoneware clays. He has by no means exhausted the opportunities for work with these clays and a lifetime of interesting investigation could be devoted to stoneware alone. The writer would say that stoneware might be better suited to our cold country than the porcelains, and these fine stonewares are always recognized as of the same high class as hard porcelains.

The term faïence has been accepted as covering a wide field that possibly might be narrowed into a field covered in Europe by the tin enameled wares at one time. We have so many types of wares that look somewhat alike but that are made at widely differing temperatures, all made from relatively coarse clays, with every type of glaze almost that can be thought of. It is in this field that the glaze maker can go his limit and he can produce warm or cold colors, brilliant or mat glazes, crystalline or amorphous glazes, anything he can find pleasure in making. It is in this type of ware the amateur finds it easy to secure adequate help from the literature and from the dealers in supplies, and since the temperatures are usually low the portable kiln is satisfactory. Any person who has had elementary chemistry can understand readily the methods used by the ceramist to develop his glazes and the field is open to any graduate of the high schools that offer chemistry, and to most college students who have had the Freshman year.

The precipitations in the tube of the chemist's laboratory show glories of colors and demand thoughtful consideration. The glazed test pieces, tiles or what not, are the test tubes of the ceramist and when series after series are run, covering every variation that can be thought of, a considerable knowledge of the properties of the complex mixtures can be had and while the reaction cannot be written out, X plus Y equals A plus B, nevertheless a very definite idea of what will happen when the same mixture is again made can be obtained and a very definite idea of what will make disaster can likewise be gained. Men like Binns and Burt and Rhead know as definitely as any chemist what to expect from certain mixings of their materials and the writer would declare that a qualitative analysis could be developed, if worth doing, dealing entirely with melted glazes, determining by fire and reagents dropped on the glazed surfaces the qualitative composition of glazes by the changes in color of either the reagent or the glaze itself.

These are some of the things that are the witcheries of glazes.

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